

UCAV – THE NEXT GENERATION AIR-SUPERIORITY FIGHTER?

BY

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DISCLAIMER

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Air Force, or Air University.

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ABSTRACT

Air superiority is an essential military mission, and will continue to be so for the foreseeable future. Control of the air is not an end of its own, but rather it provides the flexibility and freedom of action central to a full range of military capabilities. In the coming century the United States will confront a number of disparate and ambiguous challenges to its hegemony. The resources available to meet those challenges will undoubtedly be constrained. Extremely long lead times in the acquisition and procurement of new technologies mean that now, as the F-22 Raptor begins to replace the venerable F-15 Eagle, the next- generation air-superiority fighter is entering development. Unmanned aircraft must be considered as an alternative to manned aircraft for this critical mission. While cost has been the driving factor for advances in UCAV, technology has been the major limitation. This thesis concludes that an air-superiority UCAV should be feasible by the year 2025 and that it should provide an effective and affordable alternative to manned air-superiority fighters.

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CHAPTER 1

INTRODUCTION

If the enemy has air supremacy and makes full use of it, then one's own command is forced to suffer the following limitations and disadvantages: By using his strategic air force, the enemy can strangle one's own supplies, especially if they have to be carried across the sea; The enemy can wage the battle of attrition from the air; Intensive exploitation by the enemy of air superiority gives rise to far-reaching tactical limitations for one's own command.

—Field Marshall Erwin Rommel

On 17 December 1903, the Wright Brothers flew 120 feet in twelve seconds over the sands of Kill Devil Hill. The age of powered flight had arrived—from that time forward military aircraft had a profound impact on the conduct of war.¹ During World War I aircraft initially served as reconnaissance platforms but were quickly adapted to attack the enemy on and behind his own lines. The first aerial engagements were crude attempts by surface commanders to deny their adversary aerial artillery spotting and reconnaissance operations, while allowing and enhancing their own. These early missions mark the beginning of the unending quest of air forces to control and exploit the aerospace medium.² As aircraft matured, a number of advances in systems such as early warning radar, passive detection, airborne surveillance, surface-to-air missiles and anti-aircraft artillery made attempts to control that medium increasingly lethal and difficult.³ The air-superiority fighter has continually adapted to this environment and still plays a key role in modern war.

¹ Walter J. Boyne and Philip Handleman, *Brassey's Air Combat Reader* (Washington, D.C.: Brassey's, 1999) 2.

² Mike Spick, *Fighter Pilot Tactics: The Techniques of Daylight Air Combat* (New York: Stein and Day, 1983) 22-35.

³ John R. Walker, *Air Superiority Operations* (London: Brassey's, 1989) 1.

The skies over Afghanistan in the 21st century saw a new aircraft on the prowl. The Predator Unmanned Aerial Vehicle (UAV) carried Hellfire anti-armor air-to-surface missiles to fire at the targets that it detected with an amazing array of sensors.⁴ No longer were manned aircraft required to engage and destroy the fleeting targets discovered by reconnaissance aircraft. Additionally, the USAF began modifying Raytheon surface-to-air Stinger missiles to an air-to-air version that can be carried on the Predator to give it a counterair capability against enemy helicopters, cruise missiles, and unmanned aircraft.⁵ The relatively cheap and versatile Predator UAV has become America's newest air-superiority fighter.

Background and Significance of the Problem

Air superiority remains an essential military mission. Although control of the air does not itself destroy or defeat the majority of enemy forces, it provides the freedom of action and strategic flexibility that allow other military forces to do so.⁶ Air superiority is central to a full range of military capabilities, including power projection of sea and land forces, close air support, interdiction, and freedom of maneuver for ground forces. In future conflicts, American air forces could possibly face sophisticated Russian, Chinese, and allied aircraft and air defense systems that are capable of challenging current and future U.S. fighters for air superiority. These systems, although extremely expensive, have the potential to proliferate around the world in sufficient numbers to threaten U.S.

⁴ Glenn W. Goodman, Jr., "Missile-Firing Drone: USAF's Armed Predator UAV Breaks New Ground," *ISR Journal*, 2002 Issue 1, 36-38.

⁵ David A. Fulghum and Robert Wall, "Stinger Eyed for UAV Role," *Aviation Week and Space Technology*, 4 March 2002, 44.

⁶ Air superiority is not an end in itself. See Phillip S. Meilinger and John D.W. Corley, *Air Superiority: Blunting Near Sighted Criticism*, study project (Carlisle Barracks, Pennsylvania: US Army War College, 1993) 4.

regional and global interests. Planning for the future of air superiority is something that must begin today.

In the coming century the United States will confront a number of disparate, ambiguous challenges to its security. The budget to meet those challenges will most likely be severely constrained. In this fiscal environment, there will be no easy choices among weapons systems. As aerospace analyst Williamson Murray notes, “As it does with all things connected with war, American defense policy confronts ‘an option of difficulties.’ Unfortunately, hard choices are not inherently part of the American culture.”⁷ Extremely long lead times in the acquisition and procurement of new technologies mean that now, as the F-22 begins to replace the venerable F-15, the next generation aerospace superiority fighter is entering development.⁸ Technology is advancing rapidly, but costs are skyrocketing. Unmanned air vehicles (UAV) should be considered as an alternative to manned aircraft for effective and efficient completion of this critical mission.

The United States military has a long history of involvement with UAVs. The first attempt at employing a UAV was the Sperry N-9 Flying Bomb in 1918.⁹ Since that time, UAVs have had active reconnaissance roles in many American conflicts: Vietnam, OPERATION DESERT STORM, OPERATION DELIBERATE FORCE, OPERATION ALLIED FORCE, and OPERATION ENDURING FREEDOM, to name just a few. As

⁷ Williamson Murray, “Hard Choices: Fighter Procurement in the Next Century” (Cato Policy Analysis No. 334, 1991) 1.

⁸ Larry Grossman, “Fighter 2020,” *Air Force Magazine*, November 1991, 30-35. Grossman says that the Air Force’s Wright Laboratory began identifying key technologies to serve as building blocks for an air-superiority fighter to follow the F-22 in 1991, over ten years before the Raptor was scheduled to enter service.

⁹ Richard M. Clark, *Uninhabited Combat Aerial Vehicles: Airpower by the People, For the People, But Not with the People* (Maxwell AFB, Ala.: Air University Press, 2000) 7.

technologies mature and capabilities advance, the potential for UAVs to expand into other traditional military missions is progressing as well.

There is significant political pressure to develop combat capabilities in UAVs. The National Defense Authorization Act for FY 2001 states, "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology, such that by 2010, one-third of the aircraft in the operational deep-strike force are unmanned."¹⁰ UAVs will play a major role in the increasingly dynamic battle that will typify 21st century warfare.¹¹ The political and economic impetus for less risky and less costly platforms for national defense is leading to a vast expansion in the search for unmanned missions.

In 1996 the United States Air Force (USAF) Scientific Advisory Board (SAB) determined that there were nine potential mission areas for Unmanned Combat Aerial Vehicles (UCAV).¹² One of these roles was the suppression of enemy air defenses (SEAD). Boeing recently won the competition to build the USAF/Defense Advanced Research Project Agency (DARPA) X-45 SEAD UCAV advanced technology demonstrator (ATD). It has been projected that the USAF could enter development on UCAV as soon as 2003, with an initial capability possibly as early as 2005, but not later than 2008.¹³ The combination of X-45 technology, increased political emphasis and potentially lower costs means that, if a UCAV could effectively accomplish the air superiority mission, then the USAF could forego the costly simultaneous development of

¹⁰ Marty Kauchak, "UAVs Favored On The Hill," *Armed Forces Journal International*, July 2001, 12.

¹¹ David R. Oliver, *Unmanned Aerial Vehicles Roadmap, 2000-2025* (Office of Secretary of Defense, 2001) ii.

¹² Peter R. Worch, *UAV Technologies and Combat Operations* (Washington, D.C.: United States Air Force Scientific Advisory Board 1996) 2-1.

¹³ Michael Leahy, "Unmanned Combat Aerial Vehicle System Demonstration Program: UCAV Program Overview," briefing for DARPA, 18 March 2002, 47.

vehicles with overlapping qualities to replace the F-22. The potential for technology and economics to influence political decision making formulates the basis for the research question of this study.

Research Question

Is it technologically feasible and economically viable for the USAF to replace the manned air-superiority fighter with a UCAV by the year 2025?

Limitations, Assumptions and Criteria

This section presents the limitations, assumptions and evaluation criteria affecting the conclusions of this thesis.

Limitations

This study attempts to solve a problem that is still many years away. At the time of this research, many of the technological and fiscal questions are still unanswered. The further into the future that we attempt to predict, the hazier and more speculative the results. Numerous trends and models were used in an attempt to forecast technological growth and economic cost. These predictions, though, still only guess at what the future will hold. The year 2025 as the focus of this research was chosen for two reasons. First, the F-22 Raptor will have seen twenty years of operational service and may need to be replaced by then. Second, 2025 allows predictions far enough into the future yet still grounded in current capabilities. Twenty-five years of development will “accommodate the usually fifteen years required to transition a demonstrated laboratory capability into an operationally fielded system, followed by ten years of spiral development of the

system until the ultimate derivative is in production.”¹⁴ This represents the next generation of aircraft and payload technology. In other words, the technologies discussed in this paper must be currently maturing in research laboratories in order to have the possibility of being fielded in military systems by 2025.

The scope of this study is limited in many ways. The research question focuses only on the technological feasibility and economic viability of a UCAV replacement for the F-22. It does not address the political, cultural or normative influences on the process of military innovation.¹⁵ This study focuses on replacing the manned fighters rather than augmenting or complementing them. It deals with neither procurement nor doctrine. It acknowledges, however, potential impacts and implications that the development of air-superiority UCAV can have in both these areas. Finally, it focuses only on USAF operations; the operating environments and underlying missions of the other military services necessitate additional study.

The final limitation of this study is its classification level. Although there is a plethora of classified information concerning UCAV technology, the author intentionally referenced only unclassified and readily accessible sources. The result is a thesis that encompasses the majority of unclassified literature yet does not provide the complete story. The overriding intent then is to increase understanding of the efficacy and efficiency of UCAV, and promote interest and prompt further research into airpower issues of contemporary relevance.

¹⁴ Oliver, 2.

¹⁵ For excellent discussions of these factors see Richard M. Clark, *Uninhabited Combat Aerial Vehicles: Airpower by the People, For the People, But Not with the People* (Maxwell AFB, Ala.: Air University Press, 2000) and Thomas P. Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation,” (PhD diss., Johns Hopkins University, 2000)

Assumptions

The USAF purchase of the F-22 Raptor has been, and will most likely continue to be, a contentious issue. Critics and supporters alike marvel at the lethality of the machine, but the strategic need for the extremely expensive platform remains in doubt. This study, though, assumes that the USAF will continue the purchase of the F-22 as its next front-line air-superiority fighter. Whether right or wrong, the F-22 will encounter threats and attempt to maintain air superiority until it is replaced by technologies and systems that are evolving today.

Criteria

This thesis will establish desired design and performance characteristics for a successful air-superiority aircraft. It will then apply projected technological advances to these requirements to determine the combat effectiveness and efficiency of UCAV in the air superiority role. Effectiveness is a measure of capability to accomplish a military mission, while efficiency is a function of cost.¹⁶ Combat effectiveness will focus on three criteria: airframe, control and payload, to attempt to determine if UCAV can contribute in a militarily meaningful way. Efficiency will focus on both the cost efficiency (money-saving qualities) and operational efficiency (reliability and supportability) of UCAV.

Definitions

The beginning of wisdom is calling things by their right names.

—Confucius¹⁷

¹⁶ Ehrhard, 20.

¹⁷ Westenhoff, 174.

Historically, the term “air-superiority fighter” summons visions of fighter aircraft engaged in a swirling dogfight high above the battlefield. This caricature is not always correct; the description often fits but does not match the doctrinal definition or vice versa.¹⁸ An explanation of terms will be useful.

Air superiority is a means to the end of attaining military objectives. Air Force doctrine defines air superiority as, “that degree of dominance that permits friendly land, sea and air forces to operate at a given time and place without prohibitive interference by the opposing force. Air Supremacy is that degree of superiority wherein opposing air and space forces are incapable of effective interference anywhere in a given theater of operations.”¹⁹ The difference between air superiority and supremacy is the capacity of the enemy forces to interfere with friendly operations. Air supremacy connotes a degree of air superiority that does not allow an enemy the capability to conduct effective aerial operations.

Air superiority is one of six USAF core competencies. These competencies are basic areas of expertise that are made possible by the effective integration of platforms and weapons.²⁰ Air superiority is thus a condition that can be achieved by the integration of platforms and weapons. Fighter aircraft are not the only weapons in the battle for air superiority, although they figure strongly in the conflict.²¹ The term “air-superiority fighter” is therefore a misnomer, because air superiority is a condition and not a function.

¹⁸ James S. Browne, “Air Superiority Fighter Characteristics” (Leavenworth, Kansas: Command and General Staff College, 1998) 5.

¹⁹ United States Air Force, *Air Force Basic Doctrine: Air Force Doctrine Document 1* (Washington, D.C.: Government Printing Office, 1997) 29.

²⁰ *AFDD-1*, 27-28.

²¹ Walker, 3.

The mission or function of a particular aircraft best describes its contribution to a core competency.

The Air Force has sixteen enduring functions that represent the means by which forces accomplish their missions.²² Counterair missions attempt to gain and maintain air superiority through the destruction of enemy forces. Offensive counterair (OCA) takes the fight to the enemy in an effort to destroy, neutralize, or disrupt enemy air power as close to its source as possible. Defensive counterair (DCA) protects friendly forces from air and missile attack through active and passive operations.²³ It is important to note that the counterair function includes attacks on enemy forces on the surface as well as in the air. The fighter aircraft that engage and destroy enemy airborne assets have traditionally been called “air-superiority fighters”. This thesis will continue this tradition and use this description as its definition. Air-superiority fighters and air-superiority UCAVs will be designed with a primary function of attacking enemy airborne aircraft to contribute to air superiority. The many air and space forces that can perform the counterair function are integrated to attain air superiority.

The terms UAV and UCAV also have many connotations that must be defined. The UAV is “an aviation system that has as its centerpiece an uninhabited, reusable aircraft that sustains flight using onboard propulsion and aerodynamic lift.”²⁴ This definition excludes lighter-than-air craft, ballistic missiles, and cruise missiles, but leaves open the issue of flight control and autonomy. The UCAV is a small subset of UAV that carries and delivers both lethal and nonlethal weapons.

²² *AFDD-1*, 45.

²³ United States Air Force, *Air Warfare: Air Force Doctrine Document 2-1* (Washington, D.C.: Government Printing Office, 2000) 29.

²⁴ Ehrhard, viii.

Preview of Argument

Chapter Two of this thesis presents a historical perspective on the significance of the air superiority mission and the air-superiority fighter. It then establishes desired design characteristics and the performance requirements these aircraft. The chapter ends with a discussion of the F-22, which will serve as the baseline for air-superiority capabilities in 2025.

Chapter Three addresses the potential evolution and proliferation of airborne and ground-based air defense threats over the next twenty-five years. All air-superiority vehicles must be capable of surviving and accomplishing their mission in this high-threat environment.

Chapter Four discusses the components of the UCAV system. The basic workings and difficulties in each of the UCAV subsystems will be addressed to show the current level of sophistication and illustrate the areas of required emphasis.

Chapter Five discusses probable technological advances by the year 2025 and their impact on UCAVs. A series of Moore's Law-style trends are developed to forecast technological growth over this period in order to determine the technological feasibility and effectiveness of an air-superiority UCAV.

Chapter Six compares the efficiency of manned and unmanned air-superiority systems. Cost efficiency will compare the projected research and development (R&D), procurement, and operations and support (O&S) costs of manned and unmanned systems. Operational efficiency will compare the reliability, supportability, deployability and sortie generation of manned and unmanned systems.

The remaining chapters consolidate the information, determine conclusions, answer the research question, and speculate on implications for the future of air-superiority aircraft.

CHAPTER 2

THE AIR-SUPERIORITY FIGHTER

The contest for air superiority is the most important contest of all, for no other operations can be sustained if this battle is lost. To win it, we must have the best equipment, the best tactics, the freedom to use them, and the best pilots.

—General William W. Momyer, USAF

Air superiority is a necessity. Since the German attack on Poland in 1939, no country has won a war in the face of enemy air superiority, no major offensive has succeeded against an opponent who controlled the air, and no defense has sustained itself against an enemy who had air superiority. Conversely, no state has lost a war while it maintained air superiority, and attainment of air superiority consistently has been a prelude to military victory.

—Colonel John A. Warden III, USAF

From its earliest days in the skies over the battlefields on the Western Front to the skies over Baghdad and beyond, air superiority has proven itself an objective of primary importance for all military forces. The maneuverability and lethality of the air-superiority fighters has advanced quickly as technology has played an important part in the evolution of air combat tactics.²⁵ For decades, success in dogfights was a direct result of aircraft designed specifically to enhance aerodynamic performance, size and visibility. As advanced technology changed tactics to allow for the potential to employ radar missiles beyond visual ranges, the design requirements for air-superiority fighters changed also; high altitude, high-speed interceptors with avionics that allowed for long-

²⁵ Gerald A. Pelletier, “The Aerial Dogfight: A Valid Part of Today’s and Tomorrow’s Air War” (Leavenworth, Kansas: Command and General Staff College, 1990) 2.

range target detection, identification, and destruction became desired.²⁶ After combat experience proved that interceptors and bombers alone could not secure the skies, a new breed of air-superiority fighter was born. Air-superiority fighters today are designed for extreme maneuverability to ensure success in a close engagement, and stability as platforms that combine superior detection systems, weapons and stealth.²⁷

The Need for Air Superiority

Air superiority has been an enduring prerequisite to military victory during conflicts in the twenty-first century. The first aerial engagements in World War I were crude attempts by surface commanders to deny their adversary aerial artillery spotting and reconnaissance operations, while allowing and enhancing their own. These early missions mark the beginning of an unending quest by air forces to control and exploit the aerospace medium. Control of this environment became an important first step in military operations; it provided freedom to attack as well as freedom from attack.²⁸ As General Momyer and Colonel Warden put it, air superiority is the prelude to military victory—without it no conventional operations can be sustained. This is not an attempt to say that air superiority alone wins wars; on the contrary, it is rarely an end in itself. Control of the skies protects forces and permits decisive subsequent and follow-on operations by all air and surface arms. Attaining air superiority alone cannot promise victory, but it can enable the full complement of military might to become engaged.

²⁶ James S. Browne, “Air Superiority Fighter Characteristics” (Leavenworth, Kansas: Command and General Staff College, 1998) 59-75.

²⁷ Mike Spick, *Brassey’s Modern Fighters: The Ultimate Guide to In-Flight Tactics, Technology, Weapons, and Equipment* (Washington, D.C.: Brassey’s, 2000) 6.

²⁸ United States Air Force, *Air Force Basic Doctrine: Air Force Doctrine Document 1* (Washington, D.C.: Government Printing Office, 1997) 29.

Air Superiority will continue to be a vital prerequisite for military operations in the next century. Technology will advance and the nature of the enemy will inevitably change. But, as one recent study emphasized:

The ability to use the skies with impunity, while denying the same capability to an enemy, is a prerequisite for every other warfighting element of any future campaign. Without it we lose the advantages gained by the inherent speed, range, and flexibility of airpower. We also risk putting ourselves on the defensive while ceding the same advantages to our adversaries. As the precision and lethality of our weapons increases, air superiority must be gained to allow us to observe the enemy, track his activity, and react in a prompt and decisive manner, whether or not he uses (or can use) airpower in support of his own objectives, or even whether or not we choose to use (or can use) airpower in support of our objectives.²⁹

As long as aircraft are more flexible and versatile than ground forces and have the speed, range and persistence to permit concentration on any point on the surface, they will continue to have a profound impact on the nature and outcome of war. Air superiority will continue to be an essential military mission for the foreseeable future.

A Short History of the Air-superiority Fighter

On October 5, 1914, a new dimension of warfare was born—a French Voisin Type 3 of the French Air Service sent a German Aviatik down in flames as the first casualty of air-to-air combat.³⁰ For the next forty years the tactics and methods of air combat remained relatively unchanged; the objective of air-to-air combat was to maneuver the aircraft into a position from which a gun could be fired at enemy aircraft. Advances in technology greatly enhanced aerodynamic performance and firepower.

²⁹ Rick W. Lester, et al., “Counterair: The Cutting Edge” (Maxwell AFB, Ala.: Air University Press, 1996) vi.

³⁰ John H. Morrow, Jr., *The Great War in the Air: Military Aviation from 1909 to 1921* (Washington, D.C.: Smithsonian Institution Press, 1993) 64.

Specialized pursuit aircraft were designed and organized into squadrons for the sole purpose of fighting for command of the sky. Early pursuit aircraft were lightweight and highly maneuverable, with excellent pilot visibility. Guns saw such advancements as Frenchman Roland Garros's metal propeller deflector plates and Anthony Fokker's synchronization gear, but there were few advances in aircraft armament before the armistice.³¹

All of the belligerents learned a great deal about air-superiority aircraft from their experience in the First World War. Aerodynamic performance was paramount. Speed, range and maneuverability could mean life or death. Increased firepower was also needed, so manufacturers increased the caliber and number of guns to help in the struggle.³² During the interwar years enormous advances in engine technology enabled aircraft to fly faster, higher, and farther. By the late thirties aircraft had advanced from the likes of the British Sopwith Camel (top speed 113 mph, ceiling 15,000 feet, maximum range 200 miles) to aircraft like the German Messerschmitt BF-109E (top speed 357 mph, ceiling 32,800 feet, range 348 miles). This increased aerodynamic performance coupled with better firepower greatly increased the pace and lethality of the air-to-air combat environment.

The struggle for air superiority in the Second World War was greatly affected by technology. Aerodynamic performance, more powerful engines, and stronger structural integrity significantly expanded aircraft maneuverability, speed, range, and operating

³¹ David R. Mets, *Checking Six Is Not Enough: The Evolution and Future of Air Superiority Armament* (Maxwell AFB, Ala.: Air University Press, 1992) 5.

³² *Ibid.*, 6-10.

altitudes.³³ Technological evolution took these propeller-driven aircraft higher, farther, and faster. Machine guns remained the primary armament, but they were much more accurate and deadly in this war. Variations in mounting, number of barrels, and caliber were augmented with the increased accuracy provided by improved gyroscopic gunsights.³⁴ The legendary British Hawker Hurricane, German Me-109, British Spitfire, American P-40 Warhawk and P-51 Mustang were all the products of these enormous technological advances.

After World War II, the lessons learned by the United States were much different than before. The advent of nuclear weapons, jet engines and radar seemed to overshadow the performance of the air-superiority fighters. As before, America was searching for a technological answer to its problems. In 1951 an Air Force study called Project Vista dramatically changed Tactical Air Command's (TAC) focus on the future of air power. Project Vista concluded that, while the battle for air superiority was very important, it could be achieved by a concentration of tactical atomic weapons against Soviet airfields. The report also concluded that aerial dogfighting was an inefficient method of achieving air superiority.³⁵ At the same time that this study was reaching its conclusions, scientists were developing sophisticated air-to-air missiles. The two main categories were categorized by the type of guidance system employed: heat-seeking (infrared or IR) or radar-guided missiles. The purpose of these missiles was to track and destroy a flying target at ranges much greater than those afforded by the venerable machine gun. The next generation of fighter aircraft would be capable of carrying and delivering atomic

³³ Norman Franks, *Aircraft versus Aircraft: The Illustrated Story of Fighter Pilot Combat Since 1914* (New York: Macmillan Publishing Company, 1986) 66.

³⁴ *Ibid.*, 158.

³⁵ *Project Vista Final Report* (California Institute of Technology, 1952), 102, 138.

weapons and acting as high altitude interceptors. Close maneuvering, it appeared, had lost its viability in the new era of atomic weapons. But the Korean War would intervene before these changes could take place.

The Korean War was the golden era for air-superiority fighter aircraft. Technological advances produced extremely maneuverable, jet-propelled, swept-wing aircraft. Political restrictions kept bombers away from Chinese airfields and nuclear weapons off the battlefield.³⁶ New air-to-air missiles had not yet been fielded. The result was swirling dogfights over the Yalu River in a quest to control the skies. The battles were very similar to those over the Western Front forty years earlier: armed with only his aircraft and machine gun, a pilot maneuvered violently to arrive at a position at the enemy's stern to take a shot for the kill. From January to April of 1953, sixteen MiGs were downed for every F-86 destroyed.³⁷ United Nations close air support and interdiction missions proceeded unhindered. Although the war bogged down in a tactical and political stalemate, air-superiority fighters had proved their worth in the skies. It was a lesson that would soon be forgotten.

Political and military leaders viewed the Korean War as an anomaly. As such it should not have reduced emphasis on the “real” threat that was the atomic Soviet Union.³⁸ That battle would be fought with a different type of aircraft. The combination of tactical nuclear weapons and guided long-range air-to-air missiles established priorities that shifted the emphasis away from highly maneuverable fighters. The design characteristics for this type of fighter were different—it would be an extremely high-

³⁶ Conrad C. Crane, *American Airpower Strategy in Korea, 1950-1953* (Lawrence, Kansas: University of Kansas Press, 2000) 8.

³⁷ *Ibid.*, 166.

³⁸ *Ibid.*, 176.

altitude, supersonic weapons delivery platform for missiles that guided themselves to the intended target. The advance of technologies meant that opposing aircraft would probably battle without ever seeing each other.

The Vietnam conflict witnessed the first attempts to do away with the close maneuvering by using the new technology. American F-4 Phantoms had been designed as a carrier based, high altitude, high-speed fleet interceptor.³⁹ They carried no gun and relied on supersonic missiles to destroy their non-maneuvering enemies at long range. The initial engagements with the MiGs, however, showed that missiles did not always kill the adversary and that close engagements were still necessary. From August 1967 to February 1968, the North Vietnamese lost only five MiGs while downing eighteen USAF aircraft even though the MiGs had no radar-guided missiles.⁴⁰ There was a need for the interceptors, but they couldn't guarantee air superiority alone. Close-in, air-to-air combat was still a valid part of the air war.⁴¹ The Air Force quickly learned this lesson and took steps to correct the deficiencies in the future.

The USAF took two steps to restore their technological edge to maneuverability and firepower in the air-to-air arena. First, they identified and corrected specific deficiencies in the F-4. Leading edge slats and a slotted tail greatly increased the aircraft's maneuverability.⁴² A 20mm gun was added to increase firepower in close engagements. When air activities resumed over North Vietnam in 1972 after the four-year hiatus, the more maneuverable F-4 with the internal gun proved itself a formidable

³⁹ Marcelle S. Knaack, *Post-World War II Fighters: 1945-1973*, Encyclopedia of US Air Force Aircraft and Missile Systems, Volume I (Washington, D.C.: US Government Printing Office, 1978) 265-285.

⁴⁰ Mike Spick, *Fighter Pilot Tactics: The Techniques of Daylight Air Combat* (New York: Stein and Day, 1983) 153.

⁴¹ Gordon Nelson and Norm Wood, ed., "The Battle for the Skies Over North Vietnam" in *Air War – Vietnam* (New York: Arno Press, 1978) 215-245.

⁴² Knaack, 265-285.

threat at both long and short range. The new F-4 accounted for twenty-one of the forty kills achieved during the last nine months of the conflict. Eleven were the result of radar missiles and ten from ordnance in the close arena.⁴³ The dominance of the air-superiority fighter had been revived.

The second step the USAF took in the air-to-air arena was to optimize the design of its next generation of fighter aircraft. These planes would be hybrids: they would be designed to fly higher, faster and to out maneuver any other fighters airborne, as well as carry a lethal air-to-air weapons payload. They were optimized for high altitude operations and maneuverability. The F-15 and F-16 could intercept supersonic, transcontinental bombers and engage in a dogfight equally well. These aircraft would prove their mettle in many air engagements over the next three decades.

Air-superiority Fighter Design Characteristics

Technological advances during air power's first century resulted in advances in the lethality and pace of air-to-air combat. Aerodynamic performance and firepower have evolved throughout the era. Success in close engagements has normally been a result of aircraft with excellent speed, maneuverability and cockpit visibility.⁴⁴ Success in long-range engagements has resulted from aircraft with high speed and service ceiling, advanced avionics for long-range target detection, and accurate radar missiles.⁴⁵ A hybrid design compromises between the design requirements of close and long

⁴³ Robert Frank Futrell, William H. Greenhalgh, Carl Grubb, Gerald E. Hasselwander, Robert F. Jakob, and Charles A. Ravenstein, *Aces and Aerial Victories: The United States Air Force in Southeast Asia 1965-1973* (Washington, D.C.: US Government Printing Office, 1976) 123-125.

⁴⁴ Browne, 59-69.

⁴⁵ Ray Bonds, ed., *Modern Air Combat: The Aircraft, Tactics and Weapons Employed in Aerial Warfare Today* (New York: Crescent Books, 1983) 8.

engagements to create an aircraft that can excel and survive in both. These aircraft are characterized by: large airframes to carry the myriad of electronics and weapons; high-thrust, fuel-efficient engines to power both the high supersonic speeds of an interceptor or the maneuvering of a dogfighter; excellent maneuverability and cockpit visibility; and large stores of fuel to provide for long range or loiter time.⁴⁶ Technology has greatly enhanced these air-superiority aircraft.

The hybrid fighters were put to the test in the Gulf War. The air-to-air combat that occurred in the skies over Kuwait and Iraq would prove the value of America's design efforts. US dominance was so great that Iraqi leadership learned very quickly "in no uncertain terms that to fly meant to die."⁴⁷ As soon as aircraft launched, they were destroyed; after a few days they refused even to contest American control of the sky. Most of the allied air-to-air kills registered were accomplished by the AIM-7 Sparrow, a long-range radar-guided missile, while the remainder were accomplished with the AIM-9 Sidewinder, a short range, heat-seeking missile.⁴⁸ More than forty percent were the result of beyond-visual-range shots.⁴⁹ The fruits of the design process that specified a hybrid interceptor/maneuverable fighter paid off greatly with the air-superiority fighter's success in OPERATION DESERT STORM. The air-superiority fighter was integral part of the coalition counterair campaign, and subsequent designs were destined to fulfill these dual requirements.

⁴⁶ Mike Spick, *Designed For The Kill: The Jet Fighter—Development and Experience* (Shrewsbury: Airlift Publishing Ltd., 1995) 22-30.

⁴⁷ Benjamin S. Lambeth, *The Transformation of American Air Power*, (Ithaca: Cornell University Press, 2000) 114.

⁴⁸ Eliot A. Cohen, *Gulf War Air Power Survey, Volume IV: Weapons, Tactics, and Training and Space Operations* (Washington, D.C.: US Government Printing Office, 1993) 111-118.

⁴⁹ A total of 67 Sparrows were shot with 23 resulting in kills. BVR was authorized in the majority of the engagements, and no fratricide problems were encountered. A total of 11 Sidewinders were shot, resulting in 6 kills.

There are three essential design prerequisites for tomorrow's air-superiority fighter that should be emphasized: stealth, maneuverability, and cost. Since the beginning of air-to-air combat in World War I, the belligerents have endeavored to be the first in a position to shoot at their enemy. All other factors aside, the aircraft with the first shot has usually been victorious.⁵⁰ In the age of radar-guided missiles, the aircraft's radar-cross-section correlates directly to an enemy's ability to detect and thereby shoot at it. By incorporating low observable technology, an aircraft minimizes its electronic returns and delays or degrades the adversary's ability to discover and engage it. While proceeding undetected, the stealthy aircraft can get closer to his enemy to identify and shoot him first, thereby greatly enhancing the probability of victory. The same stealth advantage applies against both surface and airborne adversaries. Decreased exposure of friendly aircraft to enemy threats greatly increases their survivability and lethality in air combat.

Air-superiority aircraft should also be maneuverable for two reasons. First, maneuverability greatly enhances the survivability of aircraft in a hostile environment. As will be discussed in Chapter Three, modern air defense systems are increasingly agile and accurate. While stealth delays or degrades enemy detection, maneuverability allows aircraft to move aggressively, once detected, so as to defeat sophisticated air and ground threats. While stealth maximizes survivability before engagement, maneuverability maximizes survival while engaged.

The second reason that air-superiority aircraft should be maneuverable is that not all enemies can be defeated at long ranges. The history of close engagements shows that

⁵⁰ Anthony Thornborough, *Modern Fighter Aircraft Technology and Tactics* (Sparkford: Patrick Stephens Limited, 1995) 55-56.

maneuverability has been a key to success. At longer ranges, though, where aircraft detect and engage each other beyond visual range, maneuverability has not been as important. If all aerial engagements could successfully be conducted at long ranges, then maneuverability would be an expensive and unneeded luxury. This ideal long-range engagement cannot always occur, though, because of enemy defensive maneuvering and the constraints imposed by rules of engagement. Because enemy aircraft are detected and engaged does not necessarily mean that they will be destroyed or accede control of the skies. They will most likely react, attempting to counter or defeat missiles that have already been launched. There are a great many techniques and countermeasures that can be employed to assist in this effort.⁵¹ In this evasive manner an intelligent and well-trained adversary can close the range with modern air-superiority fighters. In Clausewitzian fashion, the adversary is a fighting, thinking and reacting enemy.

Rules of engagement (ROE) also shape air-to-air combat. ROE link political and military considerations to the tactical application of force; they delineate the circumstances and limitations under which U.S. forces will initiate or engage in combat.⁵² These constraints, for example, require American forces to properly identify enemy airborne aircraft before firing upon them. At great distances electronic identification systems must be used before long-range air-to-air missiles can be employed. Satisfying the requirements of the identification process, though, is not so easy. Restrictive ROE has negated American technological advantages on many occasions and driven aircraft to close range. This can be remedied by either easing ROE restrictions or improving the

⁵¹ Robert L. Shaw, *Fighter Combat: Tactics and Maneuvering* (Annapolis, Maryland: Naval Institute Press, 1985) 52-61.

⁵² United States Department of Defense, *Dictionary of Military and Associated Terms: Joint Publication 1-02* (Washington: Government Printing Office, 12 April 2001 as amended through 15 October 2001) 378.

capability and confidence of identification systems. ROE may be relaxed to deal with an aggressive enemy or new threat, but they will still constrain action in order to match political concerns with the application of force. Technological improvements in identification capability will greatly increase the potential engagements at long range, but not all air-to-air combat will occur there. The combination of a reactive adversaries and political restrictions may still force close engagements...air-superiority fighters should be maneuverable so they can fight in this arena.

While technology has pushed aircraft evolution, cost has been a limiting factor. Financial constraints limit the funding available to pay for new technology. Both the progress and procurement of advanced systems depend on a continuous flow of financial backing. Many distinct lobbies in the Department of Defense and the USAF are competing for the same limited funds. Combat aircraft today must balance their effectiveness, or their ability to accomplish the mission, with their expense. The number of aircraft acquired may also be constrained. As the cost of an aircraft increases, the number that can be procured decreases. Cost will always be a limiting factor; it is a fact of life in the American procurement system.

F-22 Raptor

This section reviews the capabilities of the Lockheed Martin F-22 Raptor to estimate how well it meets the established design requirements. This aircraft will carry the brunt of the weight of American air superiority efforts for many decades to come. Finally, it will serve as the standard from which to evaluate its potential UCAV replacement.

The F-22 Raptor is the result of coupling technological advances with lessons learned in aerial conflict over the past hundred years. It is a multi-role air-superiority fighter that incorporates the latest gains in stealth technology, integrated avionics, materials, engine performance and aerodynamic design. It is a hybrid fighter that is optimized for both close combat and long-range engagements; it has many advantages over the ground and airborne threats of the future. The F-22 will be at the center of America's air-superiority force for the next twenty-five years.

The design of the F-22 Raptor has been optimized for close air-to-air combat. It is powered by two Pratt and Whitney's F119 engines that provide in excess of 35,000 pounds of thrust each. The high thrust-to-weight ratio combined with advanced flight controls and two-dimensional thrust vectoring give the F-22 the capability to outmaneuver all current and projected threat aircraft. Low-drag internal weapons carriage and high operating altitudes give the Raptor superior range. A composite, thick, teardrop canopy offers excellent 360° visibility. A new generation of stealth technology significantly enhances both its survivability and lethality. As success in close engagements in the past has normally been a result of speed, maneuverability and cockpit visibility, the F-22 should benefit equally from these characteristics.

The Raptor will also excel at long-range combat and pose a serious threat to its adversaries. Supercruise is the ability to sustain supersonic flight without the use of gas-guzzling afterburner power settings. It will provide the F-22 unprecedented increases in speed, range, and endurance that will significantly reduce its exposure to enemy defenses, and increase its lethality throughout the flight envelope.⁵³ The Northrup/Grumman APG-

⁵³ Spick, *Brassey's Modern Fighters: The Ultimate Guide to In-Flight Tactics, Technology, Weapons, and Equipment*, 133.

77 active array scanning radar will give the Raptor the ability to detect and identify enemy aircraft well before its presence is known. Integrated sensors, data links, and network technologies will integrate, prioritize and display information to increase the pilot's knowledge and ensure information superiority. The addition of internal weapons carriage of AMRAAM and AIM-9 Sidewinder missiles provide it with the first-shot capability throughout the flight envelope. Additional munitions can be loaded on external stations to increase the weapons delivery capacity. As success in long-range engagements in the past has normally been the result of high speed, advanced avionics and accurate missiles, the Raptor is prepared to dominate this area of engagement also.

The development and acquisition of the F-22 has become a contentious issue. Although extremely effective, the Raptor has become very expensive at a time when there is no perceptible threat.⁵⁴ The aircraft will become operational in 2004, when it starts to replace the F-15 Eagle that is over 25 years old. The original plan to acquire 729 F-22s has been reduced to 339 aircraft, and many critics are arguing for an ultimate purchase of only 100.⁵⁵ If this plan holds true, the F-15s still flying will be approaching fifty years old by the year 2025, this study's point of transition for possible air-superiority UCAVs.

Conclusion

Air-superiority fighters have played a crucial role throughout air power's history in taking actions to gain and maintain control of the skies. Technology has pushed the evolution of aerodynamic performance and firepower to increase the pace and lethality of

⁵⁴ Michael O'Hanlon, "Congress Should Shoot Down The F-22," *The Wall Street Journal*, 2 August 1999.

⁵⁵ Ibid.

air-to-air combat, while economics have constrained them. The F-22 Raptor has been designed to carry the fight for control of the skies well into the next century, where the threats are menacing. In a sense, the Raptor represents a limit in both the cost and performance of the manned fighter. As such, it represents a reasonable point of departure for evaluating the UCAV that may replace it. The next chapter will address the probable evolution and proliferation of airborne and ground-based air defenses over the next twenty-five years.

CHAPTER 3

POTENTIAL THREAT

The Air Force has executed its responsibility to control the air so effectively over the past decades that this superiority is often taken for granted as an American birthright. Unfortunately, this is not so. We must be prepared to win freedom of action in any arena—against any adversary. We have no intention of creating a fair fight.

—General Ronald R. Fogleman

One of the most demanding imperatives facing U.S. force development across the board in the coming years will be to ensure that today's one-sided U.S. predominance over potential troublemakers remains in effect for the indefinite future.

—Benjamin S. Lambeth

American soldiers have not had to fight on battlefields without air superiority since World War II. Since that time a uniquely American way of war has emerged that places command of the air and space environment as the first objective—it has become a prelude to military victory.⁵⁶ The control of this medium provides surface forces with freedom to attack as well as freedom from attack.⁵⁷ Potential adversaries have also observed Americans and learned their own lessons; the U.S. is determined to establish air superiority over its enemies as an enabler for all other missions. As the United States and its allies have dominated the skies in the last decade over Iraq, Bosnia, Serbia and Afghanistan, the lesson has been reinforced. Prospective foes and allies alike have endeavored to develop defenses to counter U.S. dominance in the skies. Emerging air-

⁵⁶ Ibid., 313-321.

⁵⁷ United States Air Force, *Air Force Basic Doctrine: Air Force Doctrine Document 1* (Washington, D.C.: Government Printing Office, 1997) 29.

superiority aircraft, surface-to-air missiles (SAM), and advanced technology systems may challenge American air superiority efforts in the foreseeable future.

Potential Air Threats

For the past thirty years the F-15 Eagle has been the world's premier air-superiority aircraft.⁵⁸ It claimed forty Arab victims when flown by the Israelis in the Middle East wars, and twenty-six Iraqi aircraft when flown by American and Saudi pilots in the Gulf War.⁵⁹ The MiG-29 Fulcrum and Su-27 Flanker were designed to offset the strength of the Eagle and challenge it for control of the skies.⁶⁰ Some analyses estimate an approximate parity in these aircraft.⁶¹ In 1984 the initial statement of need was written that outlined the requirements for the replacement to the F-15.⁶² The F-22 was designed with this mission in mind: to extend America's air-superiority fighter preeminence until well into the next decade. While the U.S. has developed next-generation aircraft, though, so too have counters and threats to its dominance emerged. The most technologically advanced aircraft to challenge American air superiority efforts are being developed in three regions: Europe, Russia and China.

⁵⁸ Mike Spick, *Brassey's Modern Fighters: The Ultimate Guide to In-Flight Tactics, Technology, Weapons, and Equipment* (Washington, D.C.: Brassey's, 2000) 102.

⁵⁹ *Ibid.*, 98-103.

⁶⁰ *Ibid.*, 82.

⁶¹ Gen. Joseph Ralston (an Air Force officer), made the assertion that the Russian-built Su-27 and MiG-29 are already "far superior to any airplane the [United States] has today." In Richard J. Newman, "Where's the Target," *U.S. News & World Report*, October 7, 1996, p. 46.

⁶² The F-15 is considered a fourth-generation fighter. First-generation fighters were the cloth and wood biplanes and triplanes of World War I. Second-generation fighters were the stressed skin, propeller-driven monoplanes of the Second World War. Third-generation fighters were the early jet aircraft of the Korean and Vietnam conflicts. Fourth-generation fighters are hybrids, a combination of the best characteristics of the previous generations coupled with solid-state technology and beyond-visual-range avionics and weapons, such as the F-15, F-16, MiG-29 and Su-27. The fifth-generation fighter will be characterized by stealth technology, supermaneuverability, supercruise and integrated information processing avionics.

Europe

A 1995 RAND Corporation study identified three advanced European fighters currently under development that will challenge the dominance of the F-22 in the future.⁶³ The SAAB Gripen, Dassault Rafale and Eurofighter Typhoon all use advanced technology and incorporate integral load-bearing composite structures, canard configuration, relaxed stability with computerized flight controls, some degree of stealth, and advanced pilot displays and controls. The study determined that "...these European aircraft will be highly competitive with existing U.S. fighters and future variants, will be fully developed and procured, and will be sold outside of Europe." While the Gripen and Rafale are already in production, the Typhoon is expected to reach initial operational capability in June 2002. With all three fighters being aggressively promoted on the international market, the threat to U.S. air superiority is both substantial and real.

The SAAB JAS-39 Gripen is a multi-role fighter that was designed for the unique Swedish requirement for defensive short-range missions operating from dispersed highway locations.⁶⁴ It is a relatively small, single-seat, single-engine all weather, all altitude interceptor and attack aircraft. The JAS-39 incorporates a canard and delta wing design, computerized flight controls, composite construction, multi-mode radar and numerous weapons.⁶⁵ The Gripen first flew in 1988 and became operational in 1997. Although the manufacture and delivery of the main production batch of 110 aircraft should be complete in 2002, a total production approaching 300 Gripens for the Swedish Air Force is desired. Because of the high content of American components in Gripen, the

⁶³ Mark Lorell, Daniel P. Raymer, Michael Kennedy and Hugh Levaux, *The Gray Threat: Assessing the Next-Generation European Fighters* (Santa Monica: RAND, 1995) 3.

⁶⁴ *Ibid.*, 13.

⁶⁵ Paul Jackson, ed., *Jane's All the World's Aircraft 2001-2002*, 92nd ed. (Alexandria, VA: Jane's Information Group, 2001) 479-481.

U.S. can block exports of the fighter; but a dedicated variant labeled the JAS-39X that is optimized for export is currently available for purchase on the world market.⁶⁶ The Gripen combines stealth technology, excellent speed and maneuverability, and advanced avionics to create a respectable airborne threat.

The Dassault Rafale and Eurofighter Typhoon, both significantly larger than the Gripen, were designed to counter agile Russian aircraft.⁶⁷ The Rafale is a single-seat, twin-engine, multi-role fighter that combines canard and delta-wing design with graphite composite construction and fully active, computerized and digital fly-by-wire flight controls. It employs an electronically scanned, phased-array fire control radar and electro-optical infrared search-and-track system for passive long-range detection and multi-target tracking.⁶⁸ The Rafale C is expected to begin arriving in squadrons in the summer of 2002 and is expected to remain in production through 2006. Although there are no current export orders, it should be noted that the aircraft the Rafale is replacing, the Mirage-2000, is still selling on international markets. The Dassault Rafale is poised to challenge the F-22 for command of the skies around the world—it combines excellent maneuverability with advanced avionics and a vast array of weapons to create a formidable threat for the future.

The Eurofighter Typhoon is a product of the consortium of British Aerospace, Deutsche Aerospace, Alenia (Italy) and CASA (Spain) cooperative design and manufacturing. It is a single-seat, twin engine, multi-role fighter that is optimized for air superiority with excellent beyond-visual-range and close-combat capabilities. The EF-

⁶⁶ Lorell, 49-51.

⁶⁷ Mike Spick, 66. Dassault was originally involved in the Eurofighter project but international squabbling about which country should lead the design and production efforts caused the French to develop the Rafale on their own.

⁶⁸ Jackson, 117-122.

2000, which first flew in March 1994, is an outgrowth of both the British Experimental Aircraft Program (EAP) prototype program and the Messerschmitt-Bolkow-Blohm (MBB)/Deutsche Aerospace involvement in the X-31 research project.⁶⁹ It combines a canard and delta wing design with fully active, computerized fly-by-wire flight controls and a statically unstable design to provide high agility while minimizing drag.⁷⁰ The Typhoon incorporates a high concentration of graphite composite construction, semi-submerged weapon-stores stations and stealth geometry to greatly reduce the radar cross section. Advanced avionics, glass-cockpit displays and a wide assortment of air-to-air missiles round out the qualities on this highly lethal and maneuverable machine.⁷¹ Deliveries are expected to begin in June 2002 and continue through 2010. In 1999 the consortium partners announced the impending formation of the Eurofighter International (EFI) as a dedicated sales organization with a goal of securing half of the available market for eight hundred combat aircraft over the next 30 years.⁷² The potential procurement and proliferation of the Eurofighter Typhoon to nations around the world will be a real challenge to American air superiority operations.

Russia

Although the USAF says that the F-22 will be the only “true” fifth-generation fighter to enter service during the next twenty years, the Russian are actively developing two aircraft to challenge the F-22 Raptor: the MiG 1.44 MFI⁷³ and the Sukhoi S-37 Berkut.⁷⁴ The MiG 1.44 incorporates ceramic-coated, two-dimensional thrust-vectoring

⁶⁹ Spick, 58.

⁷⁰ Lorell, 9.

⁷¹ Jackson, 241-247.

⁷² Jackson, 242.

⁷³ MFI is an abbreviation for *mnogofunktsionalny frontovoy istrebitel*: multifunctional front-line fighter.

⁷⁴ John A. Tirpak, “Foreign Fighters Get Better,” *Air Force Magazine*, October 2001, 32-35.

engines and all-composite wings with sixteen control surfaces for enhanced maneuverability.⁷⁵ The avionics remain classified. The MFI will be capable of carrying all current and forecast Russian air-to-air missiles. Although the MiG 1.44 MFI is a proof-of-concept demonstrator and prototype, its technological advances could, with the infusion of substantial monetary resources or interest, be a significant threat to American air superiority operations.

The Sukhoi S-37 Berkut is a company-funded research program to explore “supermaneuverability” and stealth for the next-generation fighter.⁷⁶ It makes extensive use of composite materials and RAM coatings to significantly enhance stealth qualities. It features short, forward-swept wings that allow for higher usable lift, lower supersonic drag and better low-speed handling characteristics.⁷⁷ The S-37, like the MiG 1.44, is a technology demonstrator, and so poses no immediate threat. Although the initial S-37 prototype was not equipped with radar or weapons, it conspicuously had provisions for their later inclusion. The continuing development of advanced demonstrators shows Russian dedication to technological growth despite dire economic times. Foreign investors or increased domestic attention could lead to significant advances in a short period of time. The MiG 1.44 and S-37 could pose a threat to American control of the skies.

China

China, the only other country actively pursuing a fifth-generation fighter, is developing the Jianjiji J-10 and the Jianjiji J-12 fighter aircraft.⁷⁸ The secret J-10 is said

⁷⁵ Jackson, 399.

⁷⁶ Ibid., 444.

⁷⁷ Spick, 130.

⁷⁸ Tirpak, 35.

to be in the weight and performance class of the Eurofighter and Rafale, and is expected to be operational by 2005.⁷⁹ Chinese developers are attempting to reverse-engineer the J-10 from a single F-16 provided by Pakistan; Israeli engineers associated with the U.S.-financed Lavi fighter program that was cancelled in 1987 are assisting.⁸⁰ It is a single-engine, single-seat multi-role fighter with advanced avionics, maneuverability, armament and range. Experts think China plans to build five hundred J-10s in its initial production. The J-12 is a fifth-generation fighter projected to enter service in the 2013-2015 timeframe.⁸¹ It is being designed as a stealthy, highly maneuverable, all-weather interceptor and air-superiority fighter as a direct challenge to the F-22.⁸² These two fighters, the Jianjiji J-10 and J-12, could pose a threat to American air superiority in the 21st century.

Potential Surface-to-Air Threat

The Russians are developing the most advanced integrated air defense systems (IADS) in the world to challenge U.S. superiority in the air.⁸³ The current and future SAMs pose a significant threat to the effectiveness and survivability of airborne aircraft. They were specifically designed to counter the strengths of American technology, mainly stealth, precision and standoff weapons. All of the systems that are already in production

⁷⁹ Jackson, 66.

⁸⁰ Tirpak, 35.

⁸¹ Ibid.

⁸² "J-12 (Jianjiji-12 Fighter Aircraft 12)/F-12" *FAS Military Analysis Network*, 9 August 1999, n.p.; on-line, Internet, 8 February 2002, available from <http://www.fas.org/man/dod-101/sys/ac/row/j-12.htm>.

⁸³ Many nations are developing advanced IADS. For example, the French Aster (Mark II) is similar to the Patriot PAC-3, and Israel and the U.S. are developing the Arrow Theater Missile Defense System. The author is not attempting to imply that the U.S. will always fight a Russian-built IADS, but these systems are the most advanced in the world. In addition the Chinese IADS are copied from the Russians and built under license in China. If a selected platform can defeat the challenge presented by these threats, it should be able to handle a less sophisticated or capable threat.

and those in development are being actively marketed for export to any country that can pay.⁸⁴ The following section starts with a description of Russia's newest long range SAMs, the SA-10 and SA-12, and follows with projected capabilities of systems currently under development, the SA-20 and S-500.

The SA-10 (Russian designation S-300/S-300 PMU and Chinese designation HQ-10/ 15) is a short and medium-range, ground-based, solid-propellant, theater-defense missile.⁸⁵ It was initially designed in the 1960s and 1970s as a high-altitude surface-to-air missile with an additional capability to engage larger air-to-surface missiles.⁸⁶ Additional engagement capabilities were added incrementally: low-flying aircraft and missiles, extended range, enhanced command and control and improved electronic countermeasures. The newest version, the SA-10E (S-300 PMU2) is currently entering service with an ability to engage targets at ranges to 200 km.⁸⁷ Over ten thousand missiles and 1750 launchers were in service by 1995 in twenty countries.⁸⁸ The SA-10 Grumble, with a capability similar to the Patriot system but with significantly increased range, is an extremely lethal surface threat.

The SA-12 Gladiator/Giant (S-300V) is also classified as a short to medium-range, ground-based, theater-defense missile.⁸⁹ It is a tracked, mobile, all-altitude system with long range and extensive anti-ballistic missile (ABM), anti-cruise missile, and anti-

⁸⁴ Nikolai Sokov, "Russian Missile Defense for Europe: February 20 Proposal is More Serious Than it Seems," *Center for Nonproliferation Studies*, 14 March 2001, n.p.; on-line, Internet, 19 February 2002, available from <http://cns.miis.edu/pubs/reports/sokrmd.htm>.

⁸⁵ Duncan Lennox, ed., *Jane's Strategic Weapons*, 36th ed. (Alexandria, VA: Jane's Information Group, 2002) 306.

⁸⁶ "S-300 PMU, SA-10 Grumble, SA-N-6 Grumble, HQ-10/15 (Chinese Licensed Copy)," *FAS Nuclear Forces Guide*, 30 June 2000, n.p.; on-line, Internet, 8 February 2002, available from <http://www.fas.org/nuke/guide/russia/airdef/s-300pmu.htm>.

⁸⁷ John A. Tirpak, "The Dougle-Digit SAMS: We Didn't Encounter Them in the Gulf or in Kosovo, Next Time, We Will," *Air Force Magazine*, June 2001.

⁸⁸ Lennox, 309.

⁸⁹ *Ibid.*, 313-316.

aircraft capabilities. The guidance system for the SA-12 is similar to that of the SA-10, as it uses inertial guidance with mid-course command updates, and then track-via-missile semi-active radar in-flight. There is also a speculated active radar for terminal missile guidance; this will greatly improve the system's capability against small-radar-cross-section targets and increase its lethality against enemy aircraft. Arranged in a network with SA-10s, the SA-12 provides the first line of defense against unmanned vehicles, cruise missiles, and ballistic missiles. This mobile missile system is deployed in Russia to protect mobile SS-24 Scalpel and SS-25 Sickle ICBMs, and SCUD-B and SCUD-C surface-to-surface short-range ballistic missile systems. The SA-12 has been offered on the export market since 1992 and has since been deployed to Belarus, Ukraine, Armenia and India.⁹⁰

Russia began testing on its newest long range SAM system in early 2001. The SA-20 Triumph (S-400) is a descendent of the SA-10C (S-300 PMU). The SA-20 can employ any of the older S-300 missiles, or either of two new variants: a medium-range missile with a maximum range of 120 km, or a long-range missile with a maximum range of 400 km. Both new missiles feature a combination of semi-active and active terminal guidance.⁹¹ An over-the-horizon radar capable of six-hundred-kilometer acquisition ranges should be operational by 2003.⁹² The Russians claim that the Triumph has a significant capability against stealth technology, ballistic missiles, cruise missiles, UAV, fighter aircraft, bomber aircraft, and other standoff, high-value aircraft.⁹³ The Russians

⁹⁰ Ibid., 316.

⁹¹ "Russia Tests Triumph Long-Range SAM System," *NBCi*, March 2001, n.p.; on-line, Internet, 20 January 2002, available from <http://nbc.com/082499/aviation/s400triumph2.htm>.

⁹² "S-400 SA-20 Triumph," *FAS Nuclear Forces Guide*, 16 June 2000, n.p.; on-line, Internet, 8 February 2002, available from <http://www.fas.org/nuke/guide/russia/airdef/s-400.htm>.

⁹³ Sergei Babichev, "Triumph Advances to Firing Line," *Military Parade*, May-June 1999, n.p.; on-line, Internet, 20 January 2002, available from <http://milparade.com/1999/33/012.htm>.

have actively marketed the Triumph in the West since 2001 as a “EuroBMD” to counter the growing U.S. ABM threat.⁹⁴ The SA-20, similar to the current U.S. THAAD being developed, is touted as being twice as effective as the Patriot PAC-3, and 2.5 times more cost-effective.⁹⁵

The final advanced strategic Russian SAM in the design phase is the S-500. It is described as an upgraded version of the SA-20 (S-400) Triumph with capabilities that exceed those specified in the 1997 demarcation thresholds allowed for tactical ABM systems under the Anti-Ballistic Missile Treaty.⁹⁶ The system will supposedly be capable of engaging target missiles out to ranges up to 3,500 kilometers. Although the system has not undertaken actual development due to a lack of funding, it looms as a menacing and powerful air-superiority system. The proliferation of advanced “double-digit” SAMS is on the rise; according to the Defense Intelligence Agency (DIA), four countries had these systems in 1985. By 1995 that number had risen to fourteen and is expected to exceed twenty-two by 2005.⁹⁷ The combination of potential markets and highly lethal technology mean that surface-to-air missiles will continue to be a significant threat to aircraft for the foreseeable future.

Advanced Threats

Highly advanced technology will permit asymmetric challenges to America’s air and space superiority operations throughout the next century. Ballistic missiles, cruise

⁹⁴ Sikov.

⁹⁵ Babichev.

⁹⁶ “S-500,” *FAS Nuclear Forces Guide*, 5 August 2000, n.p.; on-line, Internet, 8 February 2002, available from <http://www.fas.org/nuke/guide/russia/airdef/s-500.htm>

⁹⁷ Thomas W. Hampton, “The Quest For Air Dominance: F-22—Cost Versus Capability,” (Maxwell AFB, Ala.: Air Command and Staff College, 1998) 12.

missiles and lasers will all represent unique challenges to U.S. forces. Aircraft must be able to survive in this extremely lethal threat environment and present viable counter-options in order to be effective in accomplishing their missions.

Ballistic missiles pose a significant threat to American counterair operations. The future conflict environment will be “characterized by the necessity for quick and absolute dominance.”⁹⁸ Allied experience in the Gulf War revealed significant weaknesses in the American capability to engage TBM, such as Hussein’s SCUD missiles. In the future, the ability to protect friendly forces from potentially hazardous theater ballistic missiles will be an absolutely essential characteristic for any air-superiority aircraft. The ability to couple a hypervelocity air intercept missile with an array of kinetic or directed energy warheads will allow an aircraft to engage and destroy TBM, air-to-air missiles, other aircraft, and high-altitude UAVs.⁹⁹ American forces, to include air-superiority fighters, must be prepared to respond to the potential ballistic missile threat.

Air-, ground- and sea-launched cruise missiles pose another significant asymmetric threat. The same advances in technology that permit expanded UAV operations have also greatly boosted potential cruise-missile operations.¹⁰⁰ Greater accuracy, flexibility and range mean increasingly dangerous weapons. Low radar-cross-section and variety of launch and attack-route options greatly increase their survivability; the potential to carry weapons of mass destruction (WMD) as well as conventional munitions greatly increase their lethality. The relatively cheap cost for development and production have resulted in an explosion of proliferation across the globe: China, Israel,

⁹⁸ Peter J. Worch, *UAV Technologies and Combat Operations*, Volume I: Summary, United States Air Force Scientific Advisory Board, November 1996, 3-3.

⁹⁹ Worch, 6-2.

¹⁰⁰ These advances will be discussed at length in the next two chapters.

South Africa, Taiwan, Iraq, Iran and North Korea all produce and aggressively export these weapons.¹⁰¹ Cruise missiles have become one method for weaker countries to vie for air superiority in future conflicts without the tremendous financial burden of modern aircraft—America no doubt will have to contend with this threat in the future.

Lasers and directed energy weapons present a menace to air-superiority aircraft. Ground-, air-, ship- and space-based lasers are currently under development in at least nine nations.¹⁰² These new weapons employ both nuclear and solid-propellant generators to power a variety of chemical lasers for use against cruise missiles, air-to-surface missiles, UAVs, and ballistic missiles. The British demonstrated the ability to successfully guide and target lasers against attacking aircraft as early as 1982.¹⁰³ At the present time the significant cost of these systems has prevented their proliferation. However, the speed at which lasers strike (the speed of light) and the scarcity of effective countermeasures to their abundant power make them a threat of the utmost importance.

Conclusion

Observant adversaries have learned that the U.S. is determined to establish air superiority over its enemies at the outset of any conflict as an enabler for all other military operations. They are taking steps to deny America the dominance that it has had over the battlefields like Iraq, Bosnia, Serbia and Afghanistan. Emerging air-superiority aircraft, SAMs and advanced technology systems will fight for command of the skies for the foreseeable future. Advanced technology is creating asymmetric threats to American

¹⁰¹ Lennox, 3-184.

¹⁰² Ibid., 239-247.

¹⁰³ Ibid., 345.

air superiority. America's next-generation air-superiority aircraft must be designed to survive and thrive in this dangerous environment.

CHAPTER 4

AIR-SUPERIORITY UCAV REQUIREMENTS

Victory smiles upon those who anticipate the changes in the character of war not upon those who wait to adapt themselves after the changes occur.
— Guilio Douhet

We have taken the charge as an obligation to find and create new ideas. We believe those ideas will make the Air Force of the future effective, affordable, and capable in seamless joint and multinational operations in which it achieves its purpose to fight and to win the Nation's wars.
— General Ronald R. Fogleman, USAF

The UAV is an aviation weapon system that operates as an uninhabited, reusable aircraft to sustain flight using onboard propulsion and aerodynamic lift. “It is a fascinating technological assemblage because the engineering challenge remains conceptually simple and operationally elusive—the achievement of flight without an onboard human pilot.”¹⁰⁴ This challenge is heightened by a UCAV, which is designed to participate in combat and operate in a hostile environment. In the face of advanced ground and airborne threats, the air-superiority UCAV of the future will be required to gain and maintain control of the skies effectively and affordably.

UCAV as a System

Broken down to its most basic parts, any UCAV consists of three primary systems: air vehicle, ground control, and payload.¹⁰⁵ The air vehicle flies, the ground control station manages the mission, and the payload represents the capability of the

¹⁰⁴ Thomas P. Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation,” (PhD diss., Johns Hopkins University, 1997) 647.

¹⁰⁵ Many sources, including the DoD UAV Roadmap 2000-2025 and DARPA identify a fourth characteristic of the system: the support segment, which includes the “ilities” (reliability, maintainability, supportability & deployability). The support segment will be discussed at length in Chapter 6, Efficiency.

UCAV to accomplish the mission. Each system is different because a UCAV that is designed to accomplish a specific mission will integrate these three systems to create an acceptable and effective platform. An air-superiority UCAV is no different. This chapter will provide a basic understanding and appreciation of each of the UCAV systems, and address the technological hurdles and mission-specific design requirements necessary for an air-superiority UCAV. This chapter lays the framework for the discussion of likely technological advancement over the next twenty-five years that will be covered in the next chapter.

Air Vehicle System

The air vehicle is the airborne portion of the UCAV system. It is normally comprised of the three components that allow the UCAV to fly: airframe, propulsion, and flight controls. The UCAV airframe usually consists of the fuselage, wings, and tail. The required capabilities for a UCAV, such as the operational ceiling, endurance, speed, and payload determine its airframe dimensions, shape and construction materials. These airframe features in turn affect the UCAV's survivability, reliability, mission effectiveness, and affordability.¹⁰⁶ Throughout the twentieth century, most of the design issues for UCAV airframes paralleled those for manned aircraft.¹⁰⁷ The same will most likely be true over the next twenty-five years. Regardless, there are still many technological hurdles in the design of UCAV airframes.

There are three airframe design considerations and advances that will be desirable in an air-superiority UCAV in 2025. First, the vehicle must incorporate stealth to enhance its survivability in the high-threat environment. Although UCAVs have always

¹⁰⁶ "UAV System Components," *UAV Center*, n.p.; on-line, Internet, 26 February 2002, available from http://www.uavcenter.com/english/10_general/13_esystem.htm.

¹⁰⁷ Ehrhard, 652.

had inherent stealth due to their small size, the design freedom generated by removing the pilot from the cockpit should allow a reduction in radar cross section that approaches the limits of passive reduction.¹⁰⁸ The problem is that stealthy designs are expensive, and their benefits must be weighed against increasing cost.¹⁰⁹ The second consideration is wing design. An adaptive wing created with smart materials and structures will significantly increase aircraft maneuverability, range and payload.¹¹⁰ The final consideration is airframe structure. An air-superiority UCAV will need high-temperature-cure graphite composite structures to significantly increase its capabilities. These structures are extremely light and strong, but very expensive.¹¹¹ Constructing a stealthy UCAV airframe made with adaptive, smart wings and graphite structures will be a significant technological challenge.

The method and type of propulsion is also a significant UCAV design consideration. Aircraft engines provide onboard propulsion and power generation to airframe and payload electronics.¹¹² Technology has traditionally imposed significant design restrictions on aircraft powerplants; requirements for extended loiter times and endurance directly conflict with the requirements for high speed and high thrust. This means that aircraft that have been designed for long on-station times have not had the thrust and maneuverability for an air-to-air engagement. There are three advanced

¹⁰⁸ Gene H. McCall, *New World Vistas: Air and Space Power for the 21st Century*, (Washington, D.C.: Government Printing Office, 1995) 8. A reduction in radar cross section by at least 12 dB in the frequency bands currently addressed will reduce the effective range of enemy radar by a factor of two and an area coverage by a factor of four. This is the limit of passive radar cross section reduction.

¹⁰⁹ The stealthy designs of the two ambitious US UAV programs, *Aquila* and *AARS*, led to massive cost overruns, severe criticism, and their eventual cancellation.

¹¹⁰ Ephraim Garcia, "Animating the Inanimate," briefing to the Defense Science and Technology Seminar, 14 May 1999, 3.

¹¹¹ Defense Technical Information Center (DTIC), *UAV Program Plan*, 1995, 8-1. (DTIC Report number ADB204601)

¹¹² Ehrhard, 651.

propulsion requirements for an air-superiority UCAV in 2025. First, the engine should incorporate a fixed geometry yaw-vectoring nozzle to significantly increase maneuverability.¹¹³ Second, the engine should employ advanced heat transfer technologies to raise UCAV speed and efficiency.¹¹⁴ Finally, for safety and logistics support reasons, the UCAV must use heavy fuels.¹¹⁵ Significant advances in propulsion technology will be necessary to create an effective and affordable air-superiority UCAV.

The final component of the air vehicle is the flight control system. This element is also the least mature and perhaps most important, because flight control system failures have historically been the largest single contributor to unmanned vehicle mishaps.¹¹⁶ In a manned aircraft the pilot monitors numerous visual, aural and somatosensory inputs to analyze the environment and determine an appropriate aircraft response. UCAVs, though, are cybernetic machines that do not analyze their environment but “simply track a few feedback variables and beyond that are perfectly blind to the environment.”¹¹⁷ The proliferation of the global positioning system (GPS) and high-speed computer processing power has solved a significant problem of UCAV flight control—location accuracy.¹¹⁸ Two additional requirements must be addressed. First, air-superiority UCAVs in 2025 must incorporate reliable autonomous control. This will ensure safe, effective and reliable mission accomplishment. Second, further development is required to create a compact, integrated, highly accurate, flight-control and management system to improve

¹¹³ Boeing Phantom Works, “Desired UCAV (SEAD) Technology Features,” *Future Aircraft Technology Enhancements (FATE) Block I Phase I*, 30 October 1997, 110; on-line, Internet, available from http://www.va.af.mil/va/techfocus/fate_studies/boeing-stl/bstl_fate1.pdf.

¹¹⁴ Ibid.

¹¹⁵ DTIC, 8-1. JP-5 and JP-8 are current versions of heavy fuels in use with aircraft.

¹¹⁶ David R. Oliver, *Unmanned Aerial Vehicles Roadmap, 2000-2025* (Office of Secretary of Defense, 2001) ii.

¹¹⁷ John D. Steinbruner, *The Cybernetic Theory of Decision* (Princeton, NJ: Princeton University Press, 1974) 57.

¹¹⁸ Ehrhard, 653.

target acquisition, flight tracking and fault tolerance.¹¹⁹ The rapid and dynamic combat environment will require significant advances in flight control technology.

Ground Control Station – the Achilles heel of the UCAV¹²⁰

While the airframe is the component that flies, the ground control station (GCS) is the component that manages and controls the mission. It is the ground support infrastructure that can vary greatly in accordance with the complexity of the mission, the concept of operation, and the UCAV's capability. The GCS has four essential functions. First, it is the primary means to control, track and operate the UCAV. Second, it is used to manipulate the payload and process air vehicle telemetry and payload data. Third, it is the communications conduit to transmit commands to the air vehicle and payload. Fourth, it provides a mission-planning and execution interface for the air vehicle operator.¹²¹ There are two components of the ground control station that add significant cost and complexity to the UCAV system—data link and autonomy.

The operator in a GCS communicates with a UCAV through a radio frequency data link. There are two types of information that cross these frequencies. First, the air vehicle transmits telemetry data that tells the vehicle operator basic flight information, such as airspeed, altitude and position. For smooth, continuous perception by the human operator this information needs to be refreshed at a rate of no less than thirty times per second.¹²² To conduct flight operations for any significant amount of time a multi-sensor feedback loop with numerous sensors and significant computational processing power is

¹¹⁹ DTIC, 8-3.

¹²⁰ Nicholas Marsh, "Issues Surrounding the Development of Unmanned Combat Air Vehicle," *United Kingdom Defense Force*, 12 June 2000, n.p.; on-line, Internet, 20 December 2001, available from <http://www.ukdf.org.uk/gr57.html>.

¹²¹ Ehrhard, 655.

¹²² Robin R. Murphy, "Evolving Autonomy: A Strategy for Development of Unmanned Vehicle Systems," 2000, 87. (Institute for Defense Analyses Paper P-3531)

required at the operator's GCS.¹²³ The second type of data the GCS receives over the data link is the information related to the payload and mission. On-board sensors and weapons can collect a vast array of information and send it in real time to the control station. To overcome the severe limitations imposed by radio line-of-sight requirements, satellites are employed to extend the operational range. These satellites are only marginally capable of filling the high data-transfer needs. Reliable radio communication between a UCAV and its operator remains a significant impediment to unmanned operations.

The current American and allied satellite communications infrastructure is incapable of supporting any sizable number of UAVs or UCAVs.¹²⁴ The bandwidth necessary to support a single video imagery feed can be estimated as follows, using extremely conservative assumptions. Start with a video image of at least 300 by 300 pixels, and eight color bits per pixel. It takes 720 kilobits to encode a single frame. At thirty frames per second, the necessary data transfer rate is 21.6 megabits per second.¹²⁵ If a 10:1 compression algorithm is used, the bandwidth requirement is reduced to 2.16 megabits per second. Present day commercial communications systems offer data rate performance ranging from 2.4 kilobits per second in the recently-defunct Iridium network (*Inmarsat-M*), to 9.6 kilobits per second in the *Globalstar* system.¹²⁶ The military *UFO* constellation supports data rates of up to 64 kilobits per second and the *Milstar* system

¹²³ Ibid., 88.

¹²⁴ Paul Eremenko, "C3I for Unmanned Combat: The Potential Impact of Unmanned Combat Vehicles on the U.S. Command, Control, Communications, and Intelligence Infrastructure and Doctrine," (master's thesis, Kennedy School of Government, Harvard University, May 2000).

¹²⁵ Ibid. The image must be updated at least 30 times per second in order to remove distortions caused by latency so that an operator can control a system in real-time.

¹²⁶ Ibid.

supports data transfer up to 2.4 kilobits per second.¹²⁷ The commercial *Teledisc* system that should reach initial operational capability (IOC) in 2004 has data transfer rates up to 2 megabits per second and *Milstar II* up to 1.5 megabits per second. Significant advances will be necessary to permit more than a few unmanned vehicles to fly at any one time.

In addition to being sufficient, the data link between the GCS and an air-superiority UCAV in the future must be available and reliable. Data-link availability refers to the geographic area or coverage for a particular satellite system. This is normally limited by orbital mechanics, the number of satellites in the system, and mission priority. An expanded network of communications satellites will greatly expand UCAV capability. Data-link reliability refers to the robustness of the signal to electronic interference. UCAVs will often operate deep in enemy territory where the jamming will be adverse.¹²⁸ “UAV will need a data link with sophisticated signal processing and anti-jam techniques such as spread spectrum and frequency hopping, backed up by robust logic which will allow the vehicle to continue its mission and return to base if the data link fails.”¹²⁹ Sufficient, available and reliable data links will be required for air-superiority UCAV operations in the future.

UCAV autonomy enhances the capability for the machine to function without input from the operator in the GCS. It can be viewed as both a policy decision and a software product. The decision to use robotic warfare is grounded in policy and has significant implications on rules of engagement and the use of force. Autonomy is also the product of an extremely complex software product called artificial intelligence (AI).

¹²⁷ Ibid.

¹²⁸ David A. Fulghum, “Aircraft, UCAVs: An Uneasy Mix,” *Aviation Week and Space Technology*, 3 August 1998, 69.

¹²⁹ Bill Sweetman, “Pilotless Fighters: Has Their Time Come?” *Jane’s International Defense Review* (June 1997) 62.

Because of its size and algorithmic complexity, AI software is perhaps the most demanding type of software to write.¹³⁰ As computing power advances to allow millions of instructions per second and programmers input billions of lines of code, inanimate machines can accomplish basic tasks.¹³¹ Highly adaptive, intelligent AI software and systems will greatly increase UCAV autonomy in the future.

UCAV control is a tradeoff between autonomy and data-link bandwidth. The previous discussion highlighted the difficulties with current data-link capabilities, which will be exacerbated with multi-spectral sensor suites and multiple airborne vehicles. Autonomy has the potential to significantly decrease data-link requirements. At one extreme, a remotely piloted vehicle with low autonomy requires all of the information needed by a human operator to be relayed via data link to a remote cockpit. This is an enormous amount of information to be conveyed via limited channels. At the opposite extreme, an autonomous UCAV with AI will have cognitive and reasoning ability similar to a human pilot. The amount of information to be transmitted in this scenario is greatly reduced and pertains only to mission accomplishment. Low intelligence and low autonomy mean that bandwidth requirements are high. On the other hand, as AI and autonomy increase, data link bandwidth decreases.¹³² Advances in both areas will be necessary to meet the needs of the future.

¹³⁰ Murphy, 91.

¹³¹ Hans Moravec, "Robots, Re-Evolving Mind," December 2000, n.p.; on-line, Internet, 1 March 2002, available from <http://www.ri.cmu.edu/~hpm/project.archive/robot.papers/2000/Cerebrum.html>.

¹³² Carlo Kopp, "The UCAV Ascendancy: What are the Problem Issues?" 15 January 2001, 6; on-line, Internet, 1 March 2002, available at <http://www.csse.monash.edu.au/~carlo/archive/MILITARY/ADFA/ucav-2001-ppt.pdf>.

Payload System

The capability of a UCAV is ultimately determined by its payload. While the air vehicle flies and the GCS manages the mission, the payload is the reason it flies.¹³³ Many modern payloads are extremely expensive, often exceeding the price of the air vehicle and GCS combined. There are two components of a UCAV payload: sensors and weapons. The majority of current UCAV sensors are centered on the traditional intelligence, surveillance and reconnaissance (ISR) roles: visible and infrared (IR) imagery, synthetic aperture radar (SAR), moving target indicator (MTI), meteorological (MET) and multispectral (MS) imaging sensors.¹³⁴ There are many other types of ISR sensors presently being developed with militarily useful roles: communications intelligence (COMINT) sensors to intercept and locate enemy communications, electronics intelligence (ELINT) systems to intercept and locate enemy radars, acoustic sensors, non-imaging IR detection, laser energy detection, nuclear radioactivity detection and chemical agent detection systems.¹³⁵ The Predator UAV is just beginning to carry weapons today, but many additional systems are under development.

An air-superiority UCAV will probably need three types of sensors: radar, IR search-and-track system (IRSTS) and self-protection sensors.¹³⁶ The radar would be the primary sensor, and has four vital functions and correlating constraints. In the search role the radar needs a high off-boresight capability and high scan rate to increase search area. In the raid-assessment role the radar needs a small beamwidth and multi-mode capability to resolve targets in close formation. In the target-identification role the radar should

¹³³ Ehrhard, 656.

¹³⁴ DTIC, 8-5 – 8-10.

¹³⁵ Ibid.

¹³⁶ Peter R. Worch, *UAV Technologies and Combat Operations* (Washington, D.C.: United States Scientific Advisory Board 1996) 5-2.

have some type of interrogator or signature identification system to identify targets at long ranges. In the fire-control mode the radar should be able to provide very precise target position and tracking to guide onboard weapons.¹³⁷ The IRSTS allows a UCAV operator to passively search, identify and shoot enemy aircraft; it should provide fire control and weapons management to IR and radar missiles. Self-protection sensors and jammers are designed to detect and deny enemy emissions and attacks. These systems should include radio frequency (RF) and electro-optical (EO) and IR sensors to protect the UCAV in a hostile environment.¹³⁸ Most of these UCAV sensors are currently available or under development for manned aircraft and systems. The most difficult part of technological advancement over the next twenty-five years will be the requirement to expand capability, decrease size and weight, decrease cost, and optimize integration of these sensors on a UCAV.

Integrating weapons into an air-superiority UCAV will be difficult. Because UCAVs will probably realize most of their initial cost and stealth advantages by being smaller than manned systems, they will have lighter payloads, use smaller weapons bays and require smaller weapons.¹³⁹ The ability to carry fewer and smaller weapons per mission means that lethality must be increased to realize the same level of mission effectiveness. “Achieving lethality with small weapons capable of being carried on small combat UAVs requires precision guidance and lethal, small warheads.”¹⁴⁰ This unique constraint has three implications for weapons employment on air-superiority UCAVs in the future.

¹³⁷ George W. Stimson, *Introduction to Airborne Radar, 2nd edition* (Mendham, New Jersey: Scitech Publishing, Inc., 1998) 41-43.

¹³⁸ Worch, 5-3 – 5-8.

¹³⁹ Ibid., 6-5 – 6-6.

¹⁴⁰ Oliver, 31.

First, the modified Stinger missile being developed for the Predator UAV is a temporary fix for an air defense problem. This small missile is a menace to other UAVs or helicopters, but has a minimal capability against advanced manned aircraft.¹⁴¹ The Stinger therefore cannot meet the future threat and will not be carried on air-superiority UCAVs. Second, directed energy weapons are ideal for use with UCAVs.¹⁴² High power microwave (HPM) and laser weapons can be both extremely lethal and precise. Although these weapons are advancing rapidly, they will initially be very large and require tremendous amounts of power. Scientists are currently being challenged to miniaturize building-size lasers to fit into large commercial aircraft.¹⁴³ The airborne laser (considered a first-generation laser), for example, will fly aboard a Boeing 747-400F aircraft and is not projected to be operational until 2009. Third-generation semiconductor laser diodes will be required to move this technology into even smaller aircraft.¹⁴⁴ Initial development and design of these technologies has not yet begun.¹⁴⁵ Until lasers have developed sufficiently, kinetic energy weapons will be employed on military UCAVs. Directed energy weapons will make significant contributions to air-superiority UCAVs in the future, but not by 2025.

Finally, the air-superiority UCAV will not be armed with a traditional gun for two reasons. First, advanced missiles are extremely lethal and reliable. The USAF learned in Vietnam that the gun was an essential weapon on air-superiority aircraft to ensure success

¹⁴¹ Duncan Lennox, ed., *Jane's Air-Launched Weapons* (Alexandria, Virginia: Jane's Information Group, 2001) 89-91.

¹⁴² Worch, 6-1 – 6-6.

¹⁴³ R. Winn Hardin, "Megawatt Laser Moves Air Defense Into New Era," *OE Reports: Technology and Trends for the International Optical Engineering Community*, April 1999, n.p., on-line, Internet, 8 May 2002, available from <http://www.spie.org/web/oer/april/apr99/cover1.html>.

¹⁴⁴ "Directed Energy Weapons: Something For a Star Wars Sequel?" *Journal of Electronic Defense*, December 1997, 37.

¹⁴⁵ "Military Lasers High and Low," *Air Force Magazine*, September 1999, x.

in close combat. Early air-to-air missiles were insufficient because they had limited employment zones, low lethality, and poor reliability.¹⁴⁶ As missile technology increased over the last forty years, though, these deficiencies were overcome. Advanced air-to-air missiles can consistently engage and destroy enemy aircraft throughout the flight envelope. Second, although simple, reliable and inexpensive, traditional guns are far too heavy to be ideal weapons on unmanned aircraft. The M61A2 20mm Vulcan Cannon being developed for the F-22 Raptor weighs 379 pounds.¹⁴⁷ The 480 rounds of ammunition add an additional 277 pounds. The total weight is 656 pounds.¹⁴⁸ An air-superiority UCAV will probably carry only four air-to-air missiles because of size and payload limitations. Each Air Intercept Missile (AIM)-120 Advanced Medium Range Air-to-Air Missile (AMRAAM) weighs 340 pounds. In order to carry a gun with capabilities comparable to those of the F-22 Raptor, each air-superiority UCAV would cut its missile load in half. The gun could be an effective weapon, but its excessive weight would significantly decrease the overall combat effectiveness of the system.¹⁴⁹

The USAF and Department of Defense have stated that an air-superiority UCAV operating in the year 2025 will be expected to carry and employ three weapons: AIM-120 AMRAAM, AIM-9 Sidewinder, and a hypervelocity missile.¹⁵⁰ The AMRAAM is currently in use throughout the US inventory. It is an active, radar-guided missile that

¹⁴⁶ Everest E. Riccioni, "The Air Superiority Fighter: A Modern Analysis," (Maxwell AFB, Ala.: Air War College, 1968) 44-45.

¹⁴⁷ The M61A2 was built specifically for the Raptor. It is a lighter version of the Air Force's venerable M61A1 that was developed in the late 1950s.

¹⁴⁸ Duncan Lennox, *Jane's Air-Launched Weapons* (Alexandria, Virginia: Jane's Information Group, 2001) 644-646.

¹⁴⁹ The only research being conducted in the United States for the use of a gun on a UCAV is the combined USN/DARPA UCAV-N, which is developing electromagnetic rail guns. These advanced guns use chemical reactions to accelerate unitary particles so as to achieve lethal ranges from 13 to 63 nautical miles. The gun on the air-superiority fighter has traditionally been used for close engagements, as air-to-air missiles work well at these longer ranges.

¹⁵⁰ Worch, 6-1 – 6-4.

enables launch-and-leave tactics and attacks against multiple enemy aircraft.¹⁵¹ The missile is equipped with a command inertial-guidance system—the aircraft’s radar steers the missile on a pre-programmed intercept trajectory based on target data obtained by the launch vehicle’s radar prior to launch.¹⁵² To employ this weapon an air-superiority UCAV will need a fire control radar with extremely precise target position and tracking data. The Sidewinder is a short range, supersonic, heat-seeking air-to-air missile.¹⁵³ An air-superiority UCAV must have some method to slave the missile’s IR seeker to the target’s IR energy source. The IR energy observed by the missile seeker is converted to electronic signals that enable the missile to acquire and track the target.¹⁵⁴ The Sidewinder and AMRAAM families of missiles are projected to be appropriate weapons for near and mid-term applications.¹⁵⁵ This means that the UCAV will not have its own air-to-air weapons, but instead must be designed to carry and employ weapons that already exist. The constraints of current weapons may be altered in the future.

A hypervelocity missile is currently being developed to accomplish boost phase intercept (BPI) of theater ballistic missiles (TBM).¹⁵⁶ In the early phase of flight the missile will be command inertial-guided. A kinetic kill vehicle (KKV) will be deployed when the interceptor approaches the target intercept zone. The KKV will employ an infrared seeker and divert thrusters to achieve a direct hit and kill on the target.¹⁵⁷ A derivative of the hypervelocity missile that can track and kill conventional air targets may

¹⁵¹ David R. Mets, *Checking Six Is Not Enough: The Evolution and Future of Air Superiority Armament* (Maxwell Air Force Base, Alabama: Air University Press, 1992) 32-34.

¹⁵² USAF Air Armament Center, *2001-2002 Weapons File* (Eglin Air Force Base, Florida: Armament Product Directorate, 2001) 1-6.

¹⁵³ *Ibid.*, 1-3, 1-8.

¹⁵⁴ “AIM-9 Sidewinder” *FAS Military Analysis Network*, 23 April 2000, n.p.; on-line, Internet, 27 February 2002, available from <http://www.fas.org/man/dod-101/sys/missile/aim-9.htm>

¹⁵⁵ Worch, 6-2 – 6-4.

¹⁵⁶ *Ibid.*

¹⁵⁷ *Ibid.*

be possible.¹⁵⁸ A UCAV carrying this missile will be required to carry a thousand-pound payload (two missiles) and loiter for long periods of time. While the Sidewinder and AMRAAM may be adequate weapons for the foreseeable future, a new generation of weapons is being developed to expand UCAV lethality.

Conclusion

A UCAV is a complex system of systems. Significant technological advances in each of its basic components are necessary to develop and design an effective and affordable air-superiority UCAV. The air vehicle—airframe, propulsion, flight controls—flies the mission. The data link and autonomy make up the ground control station, which manages the mission. The payload and weapons turn a UAV into a UCAV. The next chapter will address the potential for technological advance in each of these critical components.

¹⁵⁸ USAF Air Armament Center, 13-3, 13-9.

CHAPTER 5

AIR-SUPERIORITY UCAV FUTURE CAPABILITIES

Current Air Force interest in the field [of UAV] is centered around the traditional reconnaissance mission and the newly-emerging long-range strike role, with the vehicles carrying air-to-surface ordnance, but development of interdiction and eventually air-to-air RPV [remotely piloted vehicles] is certain to follow. The Air Force interest in RPVs is spurred primarily by cost, with new fighter aircraft such as the McDonnell Douglas F-15 already reaching unit costs within the \$15 million range.

— Aviation Week & Space Technology, 22 January 1973

The idea of an unmanned air-superiority aircraft is not new. Just as the high unit cost of the F-22 and its potential replacement is spurring high level interest in a UCAV today, the same was true of the F-15 Eagle over thirty years ago. Cost has traditionally been a driving force while technology has been the limiting factor. Development and design of unmanned vehicles has continued throughout the period. The following chapter is divided into two parts. The first section is a short history of air-superiority UCAV design and development efforts in the USAF to establish a baseline for current technological capability. The second section builds on the present technology and attempts to forecast the potential of the individual UCAV enabling technologies discussed in the last chapter.

History of the Air-superiority UCAV

In July 1970, the RAND Corporation and Air Force Systems Command (AFSC) released the proceedings of their joint symposium that advocated remotely piloted vehicles (RPV) as the future of air power.¹⁵⁹ The report declared that RPVs were

¹⁵⁹ Fred D. Orazio, "Air Superiority Panel Report," *Remotely Piloted Vehicles: An Idea Whose Time Has Come* (Santa Monica, California: RAND, 1971) 143-214. The RAND Corporation hosted the symposium

technologically feasible for a wide variety of roles, including air-to-air combat.¹⁶⁰ The air-superiority RPV was designed to be air-launched by a mother vehicle, then fly up to sixty miles to engage hostile aircraft. It was designed for a high-speed capability, with a top performance of 2.5 Mach. It was extremely maneuverable at sub- and transonic speeds, where it employed canards and an artificial stability system to achieve high angles of attack.¹⁶¹ The RPV could sustain 12-G and had a 50 to 100 percent turn rate advantage over manned aircraft across a wide speed and flight envelope.¹⁶² Once in a position of advantage the RPV would kill enemy fighters with AIM-82 IR missiles.¹⁶³

While the panel found that the system was technically feasible, it noted that:

It would be desirable to raise confidence in this concept by proceeding on an austere experimental hardware and flight program for the purpose of developing successful functional performance in such key subsystems as electro-optical sensors, flight control, communication link, and vehicle configuration, all aimed toward demonstrating the conduct of an air-to-air engagement against a manned fighter aircraft.¹⁶⁴

Additional study in propulsion, airframe subsystems and manufacturing technology was also needed to produce low-cost vehicles. The major limitations of this program were its reliance on radio line of sight, its lack of sufficient onboard sensors to cue weapons, and its very low sortie rate and reliability. With this groundbreaking study providing the

in Santa Monica, California on 19-21 May 1970, followed by reports of the various committees at conferences held 30 June to 1 July.

¹⁶⁰ Edgar Ulsamer, "Remotely Piloted Aircraft—Weapon System of the Future?" *Air Force Magazine*, October 1970, 40-44.

¹⁶¹ Fred D. Orazio, 143-146.

¹⁶² Melvin Tanchel and William B. Graham, Briefing, RAND/AFSC Symposium on Remotely Piloted Vehicles, Manager's Report, July 1970, 3.

¹⁶³ Ibid.

¹⁶⁴ Ibid.

political and bureaucratic impetus, the USAF began its quest to design an air-superiority UCAV.¹⁶⁵

As early as 1971, unmanned vehicles engaged manned fighters in air-to-air combat training. Teledyne Ryan modified their successful BFM-34 Firebee with a system dubbed MASTACS (maneuverability augmentation system for tactical air combat simulation) to create the BGM-34F fighter UAV.¹⁶⁶ This UAV had a small radar cross section (RCS), was difficult to maneuver against visually because of its small size, could sustain a 6-G turn at 25,000 feet, and could reach speeds of 1.5 Mach.¹⁶⁷ Both the USAF and USN used this UAV to train their best pilots in simulated air combat. At Tyndall Air Force Base in Florida, the BGM-34F was used as a target in the annual William Tell air combat competition. This UAV routinely outmaneuvered manned F-15 and F-16 aircraft; one named ‘Old Red’ survived eighty-two dogfights.¹⁶⁸ The USN used the MASTACS as a “graduation exercise” at their Top Gun Weapons School.¹⁶⁹ Not only could a pair of F-4 Phantom aircraft not kill the unmanned vehicle, it got behind them in less than twelve seconds.¹⁷⁰ If the UAV had been armed with air-to-air weapons it was in a position to attack and destroy the manned fighters. These accounts must be taken with a grain of salt because, although they make great stories, they represent only a small subset of military experience with UAVs. They do, however, suggest the significant potential of advanced technology and unmanned systems.

¹⁶⁵ ¹⁶⁵ Thomas P. Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation,” (PhD diss., Johns Hopkins University, 1997) 437.

¹⁶⁶ Hugh McDaid and David Oliver, *Smart Weapons: Top Secret History of Remote Controlled Airborne Weapons* (New York: Welcome Rain, 1997) 131.

¹⁶⁷ “RYAN BQM-34F Firebee II at the USAF Museum,” n.p., Internet; 19 December 2001, available from <http://www.wpafb.af.mil/museum/annex/an15.htm>.

¹⁶⁸ McDaid Oliver, 130-131.

¹⁶⁹ William Wagner, *Lightning Bugs and Other Reconnaissance Drones* (Fallbrook, California: Armed Forces Journal International and Aero Publishers, Inc., 1982) 188-189.

¹⁷⁰ Ibid.

This BGM-34F program also suffered from numerous limitations. Although this system extended the limit of range to almost two hundred miles via an airborne transmitter or airborne relay station, it was still limited to radio line of sight. The computing power was limited and the flight controls were very sensitive; it often took up to fifteen seconds to stabilize the vehicle after a change of flight path.¹⁷¹ Although the UAV could maneuver to an offensive position when under the control of a skilled operator, the challenges of integrating air-to-air weapons were numerous. These limitations combined to create a vehicle that was an excellent aid for combat training, but one that certainly could not replace a manned fighter. Despite these shortcomings, the military services have learned a tremendous amount from their experience with the BGM-34F unmanned air-superiority vehicle thirty years ago.

Beginning in 1973, NASA and the USAF teamed up to explore unmanned fighter technology. After an extensive review, the North American Aviation Division of Rockwell International was awarded a contract to conduct the three-phase Highly Maneuverable Aircraft Technology (HiMAT) project in August 1974.¹⁷² The unmanned vehicle program had two major goals: a one hundred percent increase in the aerodynamic efficiency over 1973 technology, and maneuverability that would permit a sustained 8-G turn at 0.9 Mach at an altitude of 25,000 feet. “HiMAT was essentially what the fighter designers at Rockwell International believed a future fighter plane would look like.”¹⁷³ Two aircraft flew twenty-six sorties between 1979 and 1983 in a very successful test

¹⁷¹ Ibid.

¹⁷² NASA Dryden Flight Research Center, “HiMAT: Highly Maneuverable Aircraft Technology,” *NASA Facts*, n.p., on-line, Internet; 25 February 2002, available from <http://www.dfrc.nasa.gov/PAO/PAIS/HTML/FS-025-DFRC.html>.

¹⁷³ McDaid and Oliver, 132.

project.¹⁷⁴ The HiMAT plane's rear-mounted swept wings, digital flight control system, and forward controllable canard made the plane's turn radius half the size of an F-16 and doubled the Falcon's sustained turning ability.¹⁷⁵ It also had a top speed of 1.4 Mach. Important advances were made in composite materials construction, wing structure design, digital flight control systems, and autonomous flight-control backup systems.¹⁷⁶ One analysis contended, "It simply would have been impossible to shoot one down in air-to-air combat."¹⁷⁷ Although this is likely a significant overstatement, HiMAT made impressive advances in both fighter and UAV technologies.

The HiMAT also displayed numerous technological limitations. First of all, it still had to be air-launched under a B-52 bomber. Second, it showed serious deficiencies that were the result of limited computer processing power. The microprocessor-based digital, fly-by-wire flight control system required enormous computing power; so much was needed that it could not all be placed on board the aircraft. Large, high-speed processors in the ground control station were employed to complete the flight-control calculations and then send them to the airborne vehicle. Third, the large amount of information being transferred into and out of the UAV highlighted the difficulties with data link, transfer rates, and bandwidth.¹⁷⁸ Finally, the HiMAT still carried no weapons or onboard sensors. As technology was providing the answer to some problems, it was providing constraints for others.

¹⁷⁴ Dwain A. Deets and Dana Purifoy, "Operational Concepts for Uninhabited Tactical Aircraft," (Edwards, California: NASA Dryden Flight Research Center, 1998) 12-3.

¹⁷⁵ NASA Dryden Flight Research Center.

¹⁷⁶ Ibid.

¹⁷⁷ McDaid and Oliver, 133.

¹⁷⁸ Ibid.

The X-36 was designed to carry on the research of the tailless HiMAT aircraft. Built by the Boeing Phantom Works in a cooperative engagement with the NASA Ames Research Center, this unmanned vehicle incorporated thrust vectoring and innovative aerodynamic control features to reduce weight, increase range, reduce RCS and improve survivability.¹⁷⁹ Over a twenty-five week period from 1997 to 1998, the X-36 conducted a total of thirty-one flights to explore high angles of attack at low airspeeds and low angles of attack at high speeds.¹⁸⁰ The area of specific focus was the post-stall realm where reduced airflow over the wings causes control surfaces to lose authority in maneuvering the aircraft. Unlike previous UAVs, the X-36 was also designed to take off and land under its own power. In an extension of this program, the Air Force Research Lab contracted Boeing to fly the Reconfigurable Control for Tailless Fighter Aircraft (RESTORE) software as a demonstration of the adaptability of neural-net algorithms to compensate for in-flight damage or flight control malfunctions.¹⁸¹ Two RESTORE flights were accomplished in December 1998, proving the viability of the software. The lessons learned and technological advances from these programs have not yet been made public.

Although there is little public information regarding the research other than the obligatory, “the X-36 program met or exceeded all project goals,” there has been some evidence of its limitations.¹⁸² First of all, in order to reduce cost a pilot was included in the control loop to eliminate the need for expensive and complex autonomous flight control systems, and to reduce the risks associated with automated systems’ inability to

¹⁷⁹ “Toward Future Flight,” *Spinoff*, Spring 1996, n.p., on-line, Internet; 22 February 2002, available from: <http://nctn.hq.nasa.gov/spinoff1996/18.html>.

¹⁸⁰ NASA Dryden Research Center, “X-36 Tailless Fighter Agility Research Aircraft,” *NASA Facts*, 26 November 2001, n.p., on-line, Internet; 15 March 2002, available from: <http://www.dfrc.nasa.gov/PAO/PAIS/HTML/x-36.html>.

¹⁸¹ Ibid.

¹⁸² Ibid.

deal with unknown or unforeseen phenomena once in flight.¹⁸³ In addition, in an effort to reduce cost, the X-36 reduced all redundancy. If anything had gone wrong with the UAV, an emergency parachute would have deployed to bring the X-36 softly to earth.¹⁸⁴ While these approaches to saving money may work in a research program, they highlight the difficulties that must be overcome to create reliable UCAV systems. Sidestepping these issues during developmental stages means that they will still have to be addressed in the future. Finally, data transfer and bandwidth were continuing problems. During the second test flight of the X-36 (data about only two flights has been published) the UAV lost its link and went into autonomous operation after only ten minutes of flight—the mission was scrubbed and the vehicle was eventually brought to a safe landing.¹⁸⁵ Over the last thirty years technology has come a long way, but it still has a long way to go to make an air-superiority UCAV technologically feasible.

UCAV Enabling Technologies – The Future

In the past, principal technology enablers for unmanned vehicles came from the developments for manned aircraft. Advanced sensors, high speed processing, and networking advances have thus been more aligned with those of manned aircraft.¹⁸⁶ Many of the required technology hurdles for air-superiority UCAVs over the next twenty-five years will be solved in a similar fashion, in conjunction with those for manned systems. Additional limitations that are unique to a UCAV will require the specialized

¹⁸³ John Pike, “X-36,” *FAS Military Analysis Network*, 24 December 1998, n.p., on-line, Internet; 25 February 2002, available from <http://www.fas.org/man/dod-101/sys/ac/x-36.htm>.

¹⁸⁴ McDaid and Oliver, 136.

¹⁸⁵ Laurence A. Walker, “Flight Testing the X-36: The Test Pilot’s Perspective,” (Edwards, California: NASA Dryden Flight Research Center, October 1997) 8.

¹⁸⁶ Charles L. Barry and Elihu Zimet, “UCAVs—Technological, Policy, and Operational Challenges,” *Defense Horizons*, 3 (October 2001) 7.

efforts of designers and engineers. The remainder of this chapter will analyze numerous trends and models in an attempt to estimate technological growth over the next twenty-five years. Any attempt to predict the future can be fraught with danger, and the further into the future that we attempt to look, the hazier and more speculative the results. Choosing 2025 as the target year allows predictions far enough into the future yet still grounded in current capabilities. Thus, a number of “Moore’s Law” trends will be developed by looking at recent history and present capacity in an effort to forecast future capabilities that can be compared to the requirements in the previous chapter.¹⁸⁷

Air Vehicle System

A number of technological advances are currently under design that will improve the level of performance in the air vehicle’s three primary components: airframe, propulsion, and flight controls. Airframe technology is one of the primary UCAV components that evolves in parallel with manned systems. The great strides made in the development of air-superiority UCAVs, as discussed in the previous section, have benefited both manned and unmanned platforms. The knowledge acquired in designing vehicles that employ stealth and composite-materials construction has also increased significantly. One area where continued study is required is in smart wings. This design technique—currently being researched at the Defense Advanced Research Project Agency (DARPA)—employs wing twist using shape memory alloy torque tubes, active materials, embedded fiber-optic sensors and reconfigurable structures to create adaptable

¹⁸⁷ Moore’s Law (Gordon Moore of Intel Corp.) originated in 1965 as a forecast that the capability (number of transistors on an integrated circuit) of microchip processors would double every 12 to 18 months. Based on historical performance, not physics, it has nonetheless proved useful for predicting when a given technology level will become available. The semiconductor industry has used it to define its technology roadmap for sustained growth over the past 35 years.

and responsive wings.¹⁸⁸ These advanced wings greatly increase payload, maneuverability, range, fuel economy and aerodynamic efficiency. The USAF has collaborated with DARPA to mount the airfoil on an F-18; the prototype has completed phase one and the wind tunnel tests of phase two.¹⁸⁹ The primary remaining goal of the program is to equip a UCAV with the smart wing in order to test the increases in aerodynamic and maneuvering performance. The technological advances in airframe design made through both manned and unmanned programs will likely result in significant capabilities for UCAV in the future.

The technological evolution of UAV flight control systems has also benefited greatly from advances in manned aircraft. There are two primary areas, though, where progress has focused specifically on unmanned vehicles. The first is reliable autonomous flight control. The HiMAT made significant advances in the area of reliable autonomous control. The Global Hawk high altitude endurance UAV, which can operate solely under autonomous control, continues to advance and provide daily operational experience in this critical area.¹⁹⁰ The second advance has been in precision navigation and target acquisition. The Daimler-Benz Aerospace AG Military Aircraft and Honeywell Regelsysteme GmbH have recently developed and marketed their RAPIN—a reliable, autonomous, precise integrated navigation system. This product fuses GPS, terrain reference navigation, and a laser internal navigation system through one filter to provide the UCAV with highly accurate positional tracking and target-acquisition data.¹⁹¹ Flight

¹⁸⁸ Ephraim Garcia, “Animating the Inanimate,” Presentation to the Defense Science and Technology Seminar, 14 May 1999, 2-6.

¹⁸⁹ Ibid., 6-8.

¹⁹⁰ John A. Tirpak, “Complications Overhead,” *Air Force Magazine*, April 1998, 25-26.

¹⁹¹ Thomas Kohler, Franz Tumbragel, and Jurgen Beyer, “Reliable Autonomous Precise Integrated Navigation RAPIN for Present and Future Air Vehicles,” Paper presented at the Mission Systems Panel 8th

controls are advancing quickly to meet the challenge of the dynamic combat environment.

The technology in air vehicle propulsion is also advancing at a rapid pace. Since 1988, the AFRL has conducted successful engine research as a part of its Integrated High Performance Turbine Engine Technology (IHPTET) program. The goal of this ongoing program has been to develop and demonstrate advanced engine technologies, to increase turbine engine power-to-weight ratio and to reduce fuel consumption by increasing engine efficiency through higher turbine operating temperatures.¹⁹² Although IHPTET is scheduled to conclude in 2003, its successor has already begun—the Versatile Affordable Advanced Turbine Engines (VAATE) program.

Symposium, Athens, Greece, 7-9 October 1997 (Defense Technical Center, Record accession number ADA351279), 1.

¹⁹² Mike Hirschberg, “On the Vertical Horizon: IHPTET—Power for the Future,” n.p., on-line, Internet; 30 November 2001, available from <http://www.vtol.org/ihptet.htm>.

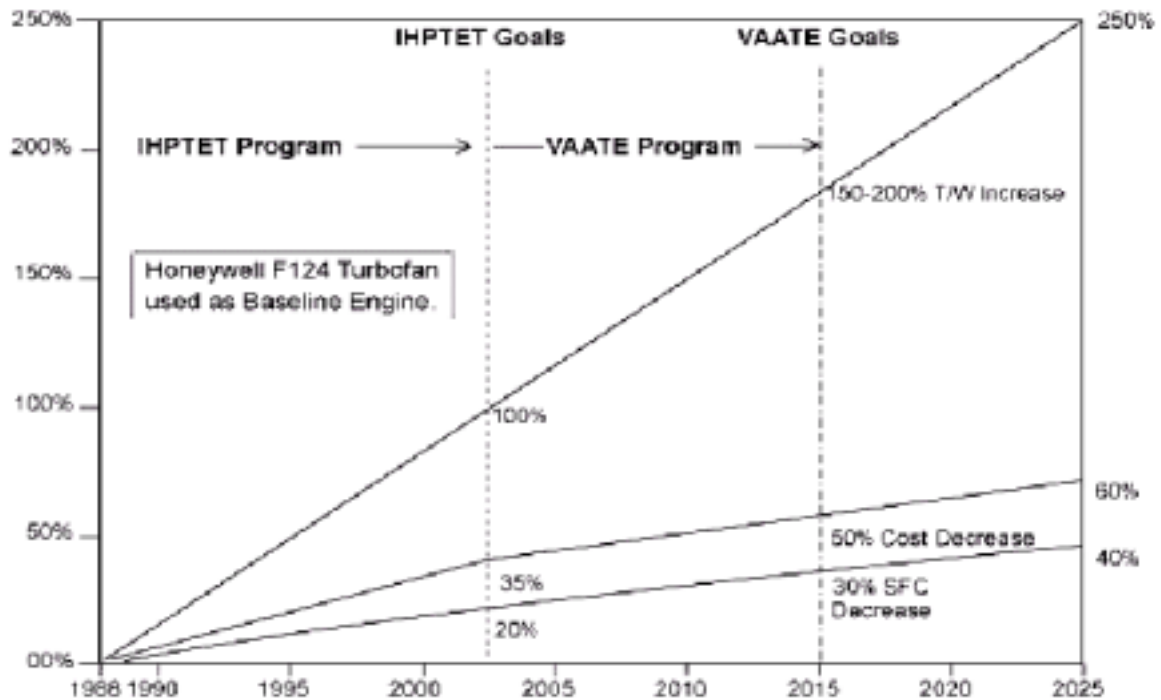


Figure 1. IHPDET and VAATE Program Goals and Trends¹⁹³

To this point IHPDET has increased the thrust-to-weight ratio of its turbine engines by forty percent, reduced specific fuel consumption (SFC) by twenty percent, and lowered engine production and maintenance costs by forty percent.¹⁹⁴ VAATE aims to further improve each of these three criteria by another fifty percent by 2015.¹⁹⁵ If these trends continue through 2025, thrust-to-weight will improve by 250 percent, SFC by forty percent and costs will be reduced by sixty percent (see Figure 1).¹⁹⁶ These are significant advances in propulsion technology. IHPDET's powerplant alone should help the USAF achieve a 3.5 Mach top speed and 2.0 Mach supercruise capability.¹⁹⁷ This would equate to a one hundred percent increase in range-loiter-payload capability for an F-15-size

¹⁹³ Ibid., 19.

¹⁹⁴ David R. Oliver, *Unmanned Aerial Vehicles Roadmap, 2000-2025* (Office of Secretary of Defense, 2001) 18.

¹⁹⁵ Ibid.

¹⁹⁶ Ibid.

¹⁹⁷ Larry Grossman, "Fighter 2020," *Air Force Magazine*, November 1991, 35.

aircraft. The added advances of VAATE and follow-on programs will also significantly improve aircraft propulsion.

New jet fuels will also increase UCAV performance. Beyond propulsion, fuel executes a second critical function in modern aircraft: it is circulated around the engine to provide a coolant before it is burned to produce thrust. The fuel's ability to absorb and transfer heat is a major limitation to existing engines. Scientists are developing a new type of jet fuel that is expected to take advantage of the major advances in refining technology that have evolved since the current aviation fuels JP-4 and JP-8 were first produced.¹⁹⁸ The new JP-900 fuel has been engineered to sustain temperatures of nine hundred degrees Fahrenheit, well over the current 575 degrees.¹⁹⁹ JP-900 exploits the additional thermal stability and heat sink realized by taking JP-8 to the supercritical phase where the fuel has properties of both a gas and a liquid.²⁰⁰ Additional research into advanced endothermic fuels will further increase the performance of jet propulsion and aircraft.

Ground Control Station

The ground control station (GCS) is the UCAV system that manages and controls the mission. Data link and autonomy present two extremely complex and complementary components of this system. Advances in data-link technology are occurring in many ways. High transfer rates in and out of the UCAV are the first challenge. Boeing is currently developing a family of low-cost, high-performance airborne phased-array antennas to provide high data rate—approximately six hundred megabytes per second

¹⁹⁸ Ibid.

¹⁹⁹ Ibid.

²⁰⁰ Richard W. Davis, "FY98 Aero Propulsion & Power Technology Area Plan," (Wright Patterson Air Force Base, Ohio: Air Force Research Laboratory, 1998) 14.

(Mbps)—and flexibility for a UCAV to rapidly and efficiently communicate with satellites, ground stations, or other aircraft.²⁰¹ Figure 2 shows the airborne data link rate trends through 2025.

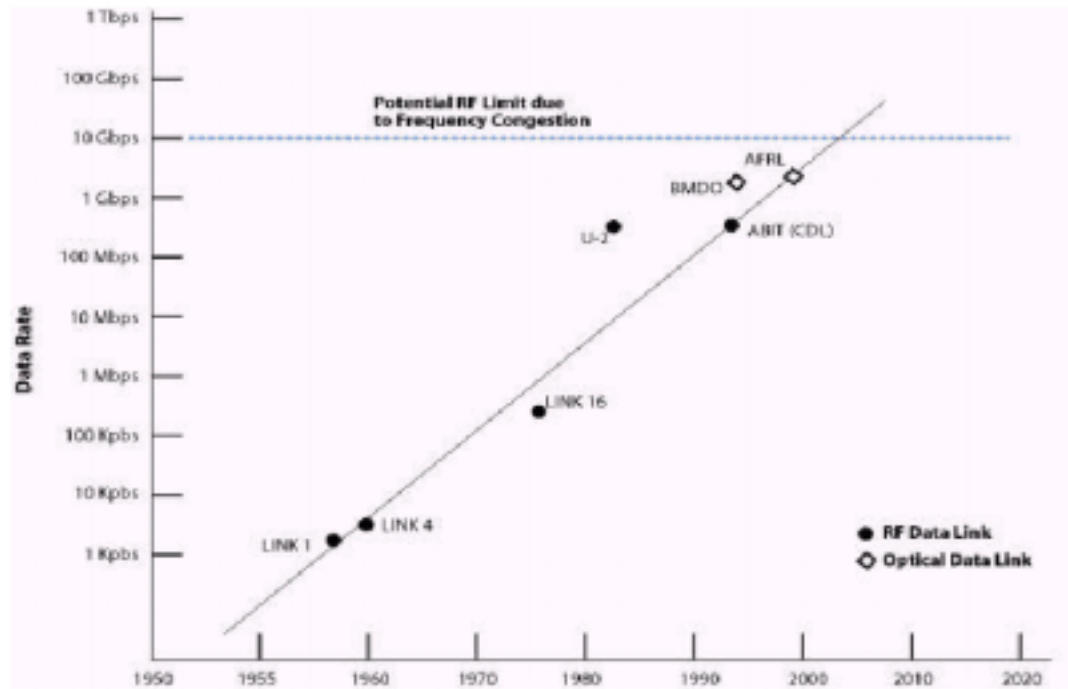


Figure 2. Airborne Data Link Data Rate Trends²⁰²

Data compression will continue to be very important as long as band-limited communications exist, “but it is unlikely that compression algorithms alone will solve the near term throughput requirements of advanced sensors.”²⁰³ Increasing capacity in satellite communications will be the result of new systems entering service. The

²⁰¹ E.L. Fleeman, “Sensor Alternatives for Future Unmanned Tactical Aircraft,” Paper presented at the Mission Systems Panel 8th Symposium, Athens Greece, 7-9 October 1997 (Defense Technical Information Center, Record accession number ADA351279), 7.

²⁰² Oliver, 33.

²⁰³ Ibid.

commercial Teledisc constellation will provide 2 Mbps transfer rates beginning in 2004 and the military Milstar II will support bandwidths up to 1.5 Mbps.²⁰⁴ More efficient bandwidth modulation methods will allow these rates to approach ten gigahertz (forty times currently fielded capabilities).²⁰⁵ A shift from the RF spectrum to IR laser data link will double or triple this advanced capacity.²⁰⁶ Data transfer rates of 1.1 terabits per second (Tbps) have already been demonstrated. Airborne and space-based Tbps laser data links will likely be possible by 2025.²⁰⁷

Increased autonomy has the potential to significantly decrease data link requirements while improving system reliability. Advances in artificial intelligence (AI) and autonomy are being approached in two ways: processing power and software.

²⁰⁴ Paul Eremenko, "C3I for Unmanned Combat: The Potential of Unmanned Combat Vehicles on U.S. Command, Control, Communications, and Intelligence Infrastructure and Doctrine," (Unpublished thesis at the Kennedy School of Government, Harvard University, 5 May 2000) 17.

²⁰⁵ Oliver, 33.

²⁰⁶ Ibid.

²⁰⁷ Ibid.

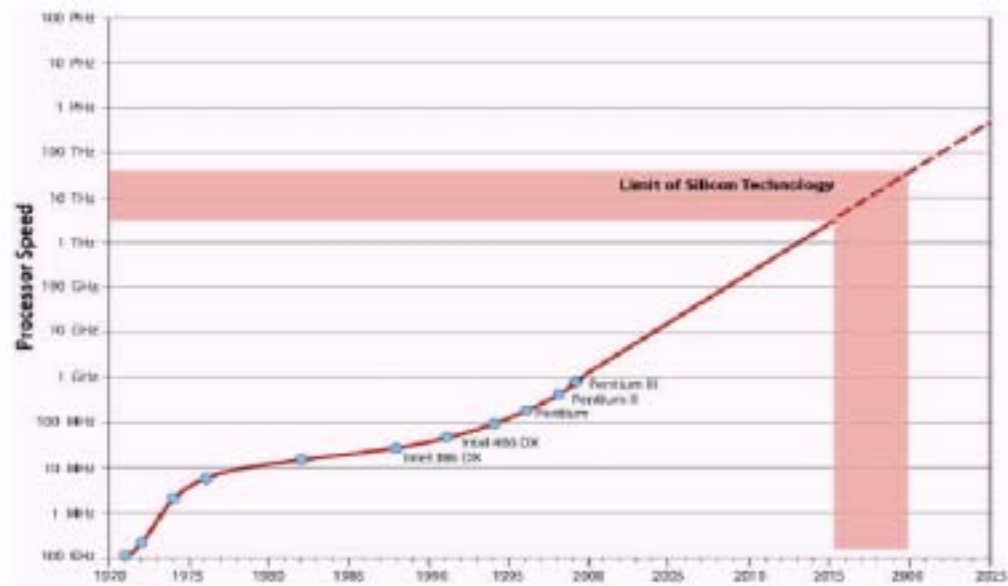


Figure 3. Processor Speed Trend.²⁰⁸

“Increased onboard processing power will be the key enabler of autonomous operations for UAVs.”²⁰⁹ Moore’s Law says that the number of transistors on a microchip will double approximately every twelve to eighteen months, which enables an equivalent increase in computing power.²¹⁰ This law has been remarkably accurate at predicting processing power over the past thirty-five years. Figure 3 is an extension of this trend twenty-five years into the future. This projection shows that 1 THz (1000 GHz) processors should become commercially available by 2013. The same rate of advance cannot be continued past approximately 2015-2020, though, because silicon-based microprocessors have a finite limit dictated by the laws of physics known as the

²⁰⁸ Ibid, 36.

²⁰⁹ Ibid, 34.

²¹⁰ Gordon E. Moore, “Cramming More Components Into Integrated Circuits,” *Electronics* 38:8 (19 April 1965).

“point-one limit.”²¹¹ This refers to the smallest dimension (0.1 micron) of a transistor obtainable before information-carrying electrons negate each other and corrupt data. Current research is attempting to extend this deadline by developing new computers that are superior to current silicon technology.²¹²

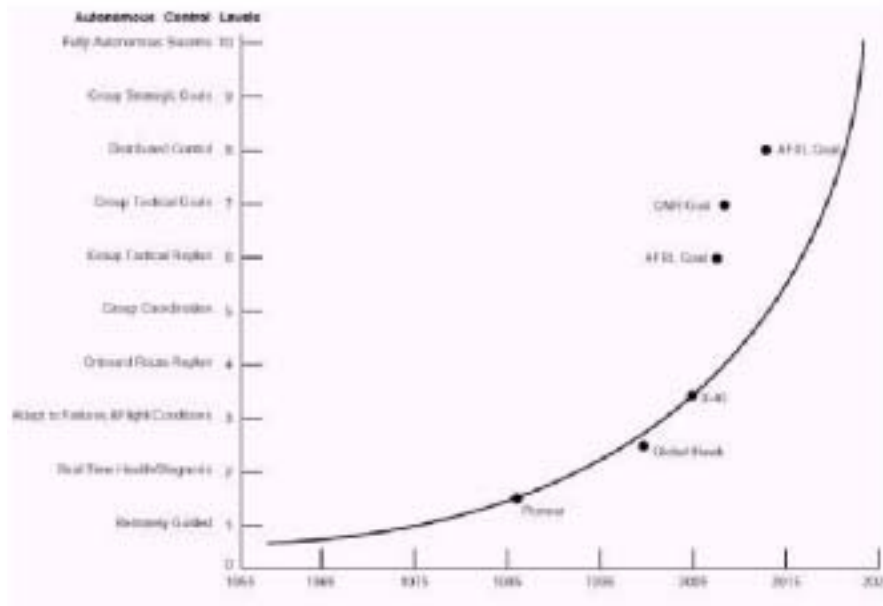


Figure 4. Autonomous Control Trend.²¹³

The AFRL has defined ten levels of unmanned system autonomous capability to serve as a standard for measuring progress. This scale runs from remotely guided (no autonomy) to fully autonomous. The USAF will attempt to demonstrate autonomous control level six (group tactical plan) by 2006, and level eight (distributed control) by 2008.²¹⁴ The projection that fully autonomous operations should be possible by 2025

²¹¹ Michio Kaku, “What Will Replace Silicon?” *Time.com*, 19 June 2000, n.p., on-line, Internet; 19 March 2002, available from http://www.time.com/time/reports/v21/tech/mag_chip.html.

²¹² Optical, biochemical, molecular and quantum processors are all currently under development and design. Optical processors should become commercially available between 2000-2005; biochemical processors approximately 2005-2025; molecular approximately 2015-2025; and quantum after 2025.

²¹³ Oliver, 35.

²¹⁴ Ibid, 35.

agrees with artificial intelligence research.²¹⁵ The trend, however, may not continue. Software performance and progression has not historically increased at the same rate as that of processing power.²¹⁶ The size and algorithmic complexity of artificial intelligence programs typically runs them over both time and budget.²¹⁷ Although a concerted effort will have to be made and close attention paid to simultaneously evolving software with hardware design, autonomous UCAV operations will make tremendous strides by 2025. The improved autonomy will significantly complement advanced processing power and data link transfer rates.

Payload System

The UCAV exists to carry some type of sensors and/or weapons airborne for a militarily useful purpose. Since the weapons that the air-superiority UCAV will be designed carry are already operational, the only possible technological advances are in sensors and overall system integration. The problem of sensors on the UCAV is being approached in two separate ways: onboard and offboard sensors. Although a basic level of sensor technology already exists on manned fighter aircraft that can perform the onboard sensor function, many improvements are being pursued. Radars have been a focus because their high cost, large size, and heavy weight preclude their use on cost-effective UCAVs. The resolution of radars has improved greatly over the past two decades through the introduction of synthetic aperture radars (SAR), in which onboard processors use the aircraft's forward motion to simulate a physically larger, fixed

²¹⁵ Noted scholar and AI expert Hans Moravec (Carnegie Mellon University Robotics Institute) projects that autonomous robots should emerge around 2030. He defines a MIPS as a million instructions per second. In 1990 computer power advanced to 1,000 MIPS. At almost 100 million MIPS (or 100 trillion instructions per second) a computer could emulate the human brain and will be able to abstract and generalize. Based on projections of potential computing power he sets 2030 as the target date.

²¹⁶ Robin R. Murphy, "Evolving Autonomy: A Strategy for Development of Unmanned Vehicle Systems," 2000, 91. (Institute for Defense Analyses Paper P-3531).

²¹⁷ Ibid, 90-92.

antenna. The result is increased system gain and thus resolution.²¹⁸ As can be seen from figure 5, in the short history of SAR advancement, the ratio of swath width covered to resolution achieved for SAR area search modes has increased about one nautical mile in width per foot of resolution every six years. This equates to the resolution of area coverage doubling every six years.²¹⁹ At the same time the weight of these systems is decreasing rapidly so that a UCAV will be able to carry an extremely high fidelity radar in the very near future.

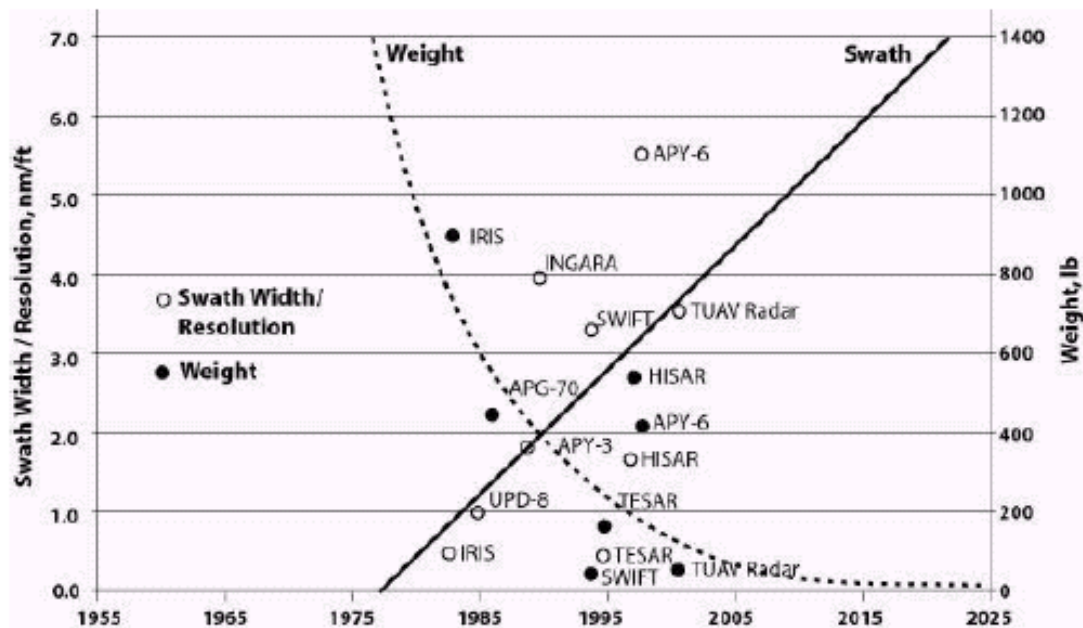


Figure 5. SAR Weight and Coverage/Resolution Trends.²²⁰

²¹⁸ Sandia National Laboratories, "What is Synthetic Aperture Radar?" n.p., on-line, Internet; 19 March 2002, available from <http://www.sandia.gov/radar/whatis.html>.

²¹⁹ Oliver, 26.

²²⁰ Ibid.

Another major research focus for onboard sensors is range-gated laser imaging radars (LIDAR). These will complement traditional radars by providing the capability to build three-dimensional images in real time.²²¹ These high-resolution images will significantly advance enemy aircraft identification and tracking. LIDAR are the first step towards advanced airborne sensors with a future goal of real-time, multiple phenomena integration to construct an accurate and complete target picture.²²² The many inputs to the UCAV system will eventually come from both onboard and offboard sensors.

The integration of offboard sensors into a linked information network is an emerging technology application with great potential. In this network, the information gathered and processed by any sensor connected to the system can be shared with the other users.²²³ These individual sensors can be positioned aboard other aircraft, UAVs, ships, and ground-based, or space-based platforms.²²⁴ The great draw of linked information networks to UCAV applications is that each individual vehicle may not be required to carry all of the necessary sensors. A formation of UCAVs, for example, could each carry one sensor and share information to create a complete picture of the environment. In the extreme a UCAV could carry no sensors at all, but instead be linked to all required information from other ground-, air-, or space-based assets. An air-superiority UCAV employed in this network could potentially shoot weapons at enemy

²²¹ R. Sica, "Exploring the Atmosphere With LIDARs," *General Introduction to LIDAR*, n.p., on-line, Internet; 19 March 2002, available from <http://pcl.physics.uwo.ca/>.

²²² Michael E. Kavaya, "LIDAR Tutorial," n.p., on-line, Internet; 19 March 2002, available from http://www.ghcc.msfc.nasa.gov/sparcle/sparcle_tutorial_morelidar.html.

²²³ Gene H. McCall, *New World Vistas: Air and Space Power for the 21st Century, Summary Volume* (USAF Scientific Advisory Board, December 1995) 20-25.

²²⁴ Bill Sweetman, "Pilotless Fighters: Has Their Time Come?" *Jane's International Defense Review*, June 1997, 58.

aircraft with completely offboard information.²²⁵ A UCAV designed in this mode could be very inexpensive yet most capable because it would carry only weapons as payload. Although it would be very difficult to provide the extremely precise target position and tracking data needed to support the AMRAAM, it would not be impossible. Cooperative engagement (a sensor on one vehicle provides missile cueing and tracking guidance for another) is an emerging operational concept that has great potential to influence the feasibility of air-superiority UCAVs.²²⁶

Conclusion

The idea of developing air-superiority UCAVs is not new. Spiraling costs have provided the impetus for innovation, but technology has been the primary limitation. The USAF has had a great deal of experience over the past thirty years designing and developing unmanned systems like the BGF-34F, HiMAT and X-36. Although technology advanced rapidly during this period, it still has a long way to go before unmanned vehicles will be able to take on combat roles. Over the next twenty-five years advances in the air vehicle, ground-control station and payload systems will be significant. These enabling technologies must come together to create an effective air-superiority UCAV. The next chapter will discuss the efficiency of unmanned systems.

²²⁵ "Data Link Systems: Providing Military Forces With Mission-Critical Equipment," *Global Defense Review*, n.p., on-line, Internet; 19 March 2002, available from <http://www.global-defence.com/99/1998/97/DataLink.html>.

²²⁶ John L. Woodward, *One Air Force...One Network: Combat Power of the Network to Every Airman* (Washington, D.C.: United States Air Force Director of Communications and Information, June 2001).

CHAPTER 6

UCAV EFFICIENCY

The primary motivating factor influencing the acceleration of development of UAV for military applications is the significant potential for cost savings. Although the combat effectiveness of a weapon system is of utmost importance, economic impact is also a necessary consideration in military procurement; the budget is not unlimited and competing requirements create pressure to keep costs down. Military utility must be balanced with cost. UCAV proponents tout their money-saving qualities. The first five chapters of this thesis addressed the potential combat effectiveness of UCAV—the capability to replace the air-superiority fighter. This chapter will consider the potential efficiency of UCAVs by comparing both the cost and operational efficiency of manned and unmanned systems.

A note of caution is required—it is difficult to compare the effectiveness and efficiency of legacy weapons with those of systems being designed. Current weapons have a history of performance from which data can be gathered. They have proven their effectiveness and efficiency. Future weapons have no history; their effectiveness and efficiency can only be estimated, calculated or expected. Differing opinions on expectations are the subject of speculation and, at times, great controversy. Government contractors and the USAF go to great lengths to gather quantitative data and to establish realistic models of expected performance, but subjectivity always enters the analysis.²²⁷

²²⁷ Thomas P. Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation,” (PhD diss., Johns Hopkins University, 1997) 20.

Although demonstrated results and potential results do not have the same level of fidelity, they can be compared as long as the reader understands the distinction.

Cost efficiency

Effectiveness is defined as the capability of a UCAV to accomplish a desired military mission. Efficiency, on the other hand, is the ability to accomplish the task as a function of resources expended.²²⁸ Cost efficiency specifically evaluates combat effectiveness per dollar spent. When discussing the affordability of UCAVs there is a tendency to focus only on the air vehicle and its constituent subsystems; the cost of UCAV should also include the interdependent elements of vehicle, weapon, and a highly integrated command and control capability.²²⁹ “A full and fair comparison of manned and unmanned aircraft costs must consider the three phases of any weapon system’s life cycle cost: development, procurement, operations and support costs.”²³⁰ The comparison should also ensure the same scenario and missions are evaluated, but should not dictate tactics or methods of operation. Achieving the desired effect is the overriding goal. A UCAV need not replicate its manned counterpart’s performance if it can functionally achieve the same mission objectives at a lower overall cost.

Research and Development Costs

The research and development (R&D) costs of unmanned and manned systems are approximately the same. R&D costs are those expenses associated with the research,

²²⁸ Ibid.

²²⁹ Peter R. Worch, *UAV Technologies and Combat Operations* (Washington, D.C.: United States Scientific Advisory Board, 1996) 4-6.

²³⁰ David R. Oliver, *Unmanned Aerial Vehicles Roadmap, 2000-2025* (Office of Secretary of Defense, 2001) 51.

development, test, and evaluation of weapon system hardware and software.²³¹ More specifically, they include the costs for feasibility studies, simulation, modeling, engineering design, development, fabrication, assembly, prototype testing, support equipment, initial system evaluation, and training equipment and services.²³²

Table 1. Manned vs. Unmanned Aircraft Development Costs

Mission/Aircraft	Program Start	First Flight	Interval	Type of Program/ Program Sponsor	Cost to First Flight (\$FY00)
Reconnaissance					
U-2	Dec 54	Aug 55	8 mos	SAP*/CIA	\$243M
RQ-4/Global Hawk	Oct 94	Feb 98	41	ACTD/DARPA	\$205M
Attack/Strike					
F-16	Feb 72	Jan 74	23	DAB*/USAF	\$103M
X-45/UCAV	Apr 98	Mar 01	35	ATD/DARPA	\$102M
Reconnaissance, Penetrating					
SR-71	Aug 59	Apr 62	32	SAP/CIA	\$915M
D-21	Mar 63	Feb 65	23	SAP/USAF	\$174M
Stealth					
XST/Have Blue (F-117)	Apr 76	Dec 77	20	SAP/USAF	\$103M
RQ-3/DarkStar	Jun 94	Mar 96	21	ACTD/DARPA	\$134M
*SAP = Special Access Program; DAB = Defense Acquisition Board (Milestone Process)					

Source: UAV Roadmap, page 53.

Table 1 shows the historical costs to reach first flight for manned and unmanned aircraft. This table shows that historically R&D costs are essentially the same. “This is reasonable given that the engineering required to get a new design airborne is driven more by aerodynamics and propulsion than by human factors and avionics.”²³³ There is no reason to believe that the equivalency in spending on manned and unmanned systems in the future will not follow this trend. There is little potential for UCAV R&D savings in the future.

²³¹ Thomas E. May, “Operating and Support Cost Estimating: A Primer” (Maxwell AFB, Ala.: Air Command and Staff College, 1982) 2-1.

²³² Kenneth E. Marks, H. Garrison Massey, and Brent D. Bradley, *An Appraisal of Models Used in Life Cycle Cost Estimation for USAF Aircraft Systems* (Santa Monica, California: Rand, 1978) 11.

²³³ Oliver, 51.

Procurement Costs

The procurement costs for manned and unmanned systems are also essentially the same. Procurement costs are those expenses associated with producing the aircraft, initial support equipment, training, technical and management data, quality control, and the initial spares and repair parts required to introduce a new system into the inventory.²³⁴ The aviation industry has long recognized an informal rule, based on historical experience, that the procurement cost of an aircraft is directly proportional to its empty weight.²³⁵ The cost per pound of the F-22 Raptor is projected to be \$3125.²³⁶ The pilot and supporting subsystems (ejection seat, displays, oxygen system, pressurization system, survival equipment, canopy) in manned aircraft are conservatively estimated to account for five percent of aircraft weight.²³⁷ In the F-22 this will account for 2000 pounds. According to this informal rule, over \$6 million of the cost for each Raptor could be eliminated simply by removing the pilot from the aircraft. Manned aircraft costs compare with the current composite aircraft structure cost of \$1500 to \$2000 per pound and UCAV target cost of \$1000 per pound.²³⁸ Additionally, removing the pilot from the cockpit would allow engineers to reduce aircraft size as much as forty percent and still attain equal vehicle performance, range and payload.²³⁹ Even greater weight savings will

²³⁴ Benjamin S. Blanchard, *Design and Manage to Life Cycle Cost* (Portland, Oregon: M/A Press, 1978) 10.

²³⁵ This rule comes from a standard parametric model for estimating life cycle costs called the Burns Model. The model uses a judgment factor for computing airframe engineering hours for development and production to account for advanced technology features such as stealth, vectored thrust and maximum speed. The cost estimation methodology has been verified by correlating estimated cost with published cost for a number of military and commercial aircraft. See Wayne J. Burns, *Aircraft Cost Estimation Methodology and Value of a Pound Derivation for Preliminary Design Development Applications*, SAWE Paper No. 2228, Long Beach, CA 23-25 May 1994.

²³⁶ According to the USAF F-22 Raptor Fact Sheet the empty weight of the F-22 is 40,000 pounds. The Congressional Budget Office estimates the production cost for each aircraft to be \$125 million. The cost per pound is \$3125.

²³⁷ Worch, 4-8.

²³⁸ Ibid., 4-5.

²³⁹ Stacey Evers, "Unmanned Fighters: Flight Without Limits," *Jane's Defence Weekly*, 10 April 1996, 29.

result from reduced load margins, reduced levels of redundancy, and increased use of composite structures.²⁴⁰ All of these factors combine to show that there is a significant potential for savings in the procurement of UCAV aerial vehicles.

Any potential savings in the procurement of the UCAV air vehicle are offset by the expenses of required ground equipment. Procurement cost calculations for a UCAV must include the development and purchase of expensive ground control stations (GCS) and storage containers. These two components are critical portions of the entire UCAV system. Although GCS are one-time investments and they can control many UCAV with one station, their initial costs are significant. Ground storage containers will also require a hefty one-time purchase to protect UCAVs. Protective storage units that maintain relative humidity and allow rapid reconstitution of UCAVs in storage to meet deployment or exercise requirements are a critical part of the concept of operations for UCAVs—they form the basis for the extensive operations and support cost savings.²⁴¹ The expense of GCS and UCAV storage containers effectively negates the aerial vehicle procurement savings. The end result is that, at least initially, procurement costs for manned and unmanned systems are essentially equal.

Operations and Support Costs

Unmanned systems have the potential for significant savings over manned systems in operations and support (O&S) costs. O&S costs are the sum of costs of program fuel, oil, lubricants, training, spares, depots, and facilities required to operate, maintain and support the hardware and software of the system.²⁴² Variables such as

²⁴⁰ Worch, 4-8.

²⁴¹ Michael Leahy, “Unmanned Combat Air Vehicle system Demonstration Program: UCAV Program Overview,” briefing for the Defense Advanced Research Project Agency (DARPA), 18 March 2002, 10.

²⁴² May, 2-1.

aircraft type, maintenance man hours per flight hour, type and number of missions, annual utilization, number of airplanes acquired and crew strength all influence O&S costs.²⁴³ Under the current Air Combat Command (ACC) UCAV concept of operations (CONOPS) the air vehicles would remain in dormant storage until they were needed in combat, when they would be loaded onto cargo aircraft and transported to a theater of operations.²⁴⁴ Only minimal training would be conducted actually flying the UCAV. Instead the operators would gain necessary experience and develop tactics using high-fidelity simulators.²⁴⁵ This concept of operations could potentially result in significant savings in both wartime and peacetime O&S costs.

UCAVs could suffer a substantially higher combat loss rate than manned aircraft and still be cost efficient. Fifty percent of a UCAV's designed flying life would be spent in combat operations under the ACC CONOPS.²⁴⁶ A manned fighter aircraft, however, will spend almost 95 percent of its inflight life conducting training sorties.²⁴⁷ A JSF, for example, will cost \$65 million and is designed for a flying life of eight thousand hours—only four hundred of these will be spent supporting combat operations.²⁴⁸ An X-45 UCAV will cost only \$15 million for five thousand flight hours. The cost per combat flying hour of the JSF is projected to be \$162,500 and the X-45 \$6000. This difference implies that UCAVs could suffer 27 times the combat loss rate of JSF and still be cost

²⁴³ V.E. Jayakrishnan, "Model for Aircraft Life cycle Cost Estimation," August 2001, 4; on-line, Internet, 22 February 2002, available from <http://www.cse.iitb.ernet.in/model.htm>.

²⁴⁴ David Hiltz, "Air Combat Command UCAV CONOPS," Briefing on 25 June 2001, 11.

²⁴⁵ John A. Tirpak, "UCAVs Move Toward Feasibility," *Air Force Magazine*, March 1999, 34.

²⁴⁶ ACC Conops 12.

²⁴⁷ Oliver, 54.

²⁴⁸ The projected cost of the JSF is \$65 million based on congressional budget estimates. Lane Pierrot, *A Look at Tomorrow's Tactical Air Forces* (Washington, D.C.: Congressional Budget Office, 1997), 35.

efficient by standards applied to today's manned fighters.²⁴⁹ This amounts to a significant savings in wartime O&S costs.

The potential savings in peacetime O&S is even greater. Human error is directly responsible for seventy percent of peacetime aircraft losses. It is a contributing factor to a large percentage of the remaining mishaps.²⁵⁰ Although a rigorous safety program conducts investigations, modifies aircraft and alters procedures, the percentage of accidents attributed to the human operator has remained fairly stable over time. There are three factors that can potentially reduce the rate of human error in unmanned vehicle operations. First, UAVs have demonstrated the ability to operate autonomously.²⁵¹ Although the physical cues, accelerations and vibrations of the aircraft are lacking in the GCS, a redundant digital automatic flight control system can now direct the vehicle to a safe landing.²⁵² Second, since operators at computer workstations remotely control UCAVs, there is no need to fly continual training missions to hone their skills. Much more cost efficient simulators could replace the majority of expensive training missions currently conducted in aircraft. The simulator could be indistinguishable from actual sorties, and an extensive range and depth of training could be conducted from an operator's console. Third, with these advanced simulators the amount of time UCAVs actually spend flying can be greatly reduced. It was calculated in FY2000 that the USAF spends over \$1 billion a year keeping the two thousand F-16 Fighting Falcon pilots in

²⁴⁹ Oliver, 54.

²⁵⁰ There is a considerable amount of data available on USAF aircraft mishaps. The Air Force Safety Agency at Kirtland AFB, NM collects, compiles, analyzes and publishes statistics on all manned USAF aircraft. See: <http://www-afsc.saia.af.mil>.

²⁵¹ Oliver, 54.

²⁵² John H. DelFrate and Gary B. Consentino, *Recent Flight Test Experience With Uninhabited Aerial Vehicles at the NASA Dryden Flight Research Center* (Edwards, California: National Aeronautics and Space Administration, April 1998) 4-9.

peak flying condition.²⁵³ In contrast, the UCAV force will require only a small fraction of that price. Keeping the air vehicles on the ground can also lower attrition expenditures. Of the 265 total USAF F-16 losses to date only four occurred in combat while the remainder (98 percent) have been the result of training accidents.²⁵⁴ Unmanned peacetime O&S savings could potentially approach ninety percent.²⁵⁵ The combination of wartime and peacetime expenditures combine to show that unmanned systems have the potential for considerable O&S life cycle cost savings.

Operational efficiency

Operational efficiency contributes to both combat effectiveness and cost efficiency. It combines the factors of reliability and supportability to determine how well a weapon system can accomplish its mission in an actual combat environment. A highly effective, cost-efficient vehicle that crashes, is shot down, or aborts the majority of its tasked missions contributes little to overall success. Extensive maintenance and support requirements can also severely limit deployments and sortie rates. Consistency, dependency and simplicity, on the other hand, magnify performance and instill confidence in combat units.²⁵⁶

Reliability

Although today's UAVs tend to cost less than their manned counterparts, this savings is achieved largely by sacrifices in reliability—omitting

²⁵³ “Look, No Pilot,” *The Economist*, 11 November 2000, 101-102.

²⁵⁴ Oliver, 55.

²⁵⁵ Worch, 4-7. DARPA and several organizations have conducted numerous studies that place the range of savings between 80 – 90%.

²⁵⁶ Ehrhard, 49-50.

system redundancy and using components not originally developed for use in the flight environment—shortcuts which would be unacceptable if an aircrew is involved.²⁵⁷

The reliability of unmanned vehicles has historically been very low...they suffer accident rates ten to a hundred times higher than those of manned systems.²⁵⁸ Accidents or hostile fire have already claimed almost one-third of the total Predator UAVs procured by the USAF.²⁵⁹ Reliability is the probability that a weapon system will successfully conduct its mission under desired conditions.²⁶⁰ It is influenced by vehicle accident rate, part failure rates (expressed in mean time between failures) and overall survival rate. A low reliability rate decreases combat effectiveness because there is less probability that a desired mission will be accomplished on time. At the same time, a low reliability rate also decreases cost efficiency by requiring more vehicles to be allocated to a given mission in order to achieve an acceptable level of confidence that the mission will be successful. Although the reliability of unmanned vehicles is comparatively low, the USAF is attempting to counter this trend with advanced technology.

Increased technology is a double-edged sword for UAVs. The advances discussed in chapter five can have an extensive impact on the three leading causes of unmanned mishaps: operator error, loss of propulsion, and flight control system malfunctions. These advances, though, do not come cheap. UAV improvements that

²⁵⁷ Oliver, 17.

²⁵⁸ Ibid.

²⁵⁹ Ron Laurenzo, "Air Force Has Lost One Third Of Its Predators," *Defense Week*, 8 April 2002, 2.

²⁶⁰ Blanchard, 236-238.

yield increased reliability inevitably increase system cost.²⁶¹ As the cost of the vehicle increases, higher reliability becomes necessary to protect the added investment. This process frequently spirals out of control with an end product that is far less effective and more expensive than desired.²⁶² A balance must be struck that provides the UAV sufficient reliability at an acceptable price. Unmanned system reliability needs to be advanced considerably.

Supportability

Unmanned systems are being designed to be very supportable. Supportability is an inherent characteristic of equipment design that considers ease of use, economy, safety and mobility of performance for support operations.²⁶³ It is comprised of four attributes: storability, deployability, sustainability, and maintainability.²⁶⁴ UCAVs are being designed to remain in storage for over ten years then be unpacked, reassembled, and made mission-ready in less than a half hour.²⁶⁵ While still in their crates, six UCAVs can be loaded into a C-17 (twelve in a C-5) for quick transportation to contingencies around the globe.²⁶⁶ To enhance logistics and sustainability, DARPA is developing an “autonomic” support system to monitor reliability rates, track spare equipment requirements, and integrate parts orders and deliveries into current Air Force

²⁶¹ Charles L. Barry and Elihu Zimet, “UCAVs—Technological, Policy, and Operational Challenges,” *Defense Horizons*, October 2001, 7.

²⁶² This same process of spiraling costs and requirements has been experienced many times over the last forty years in DoD with UAVs. It has led to the enormous cost overruns and performance failures that have canceled major development projects. The failure of these programs still haunts UAV development in the U.S. today. For an excellent discussion of this topic see Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation.”

²⁶³ Blanchard, 230-231.

²⁶⁴ These components are commonly known as the “ilities”. The process of incorporating these elements into a UCAV system links cost efficiency to combat effectiveness.

²⁶⁵ John A. Tirpak, “Send in the UCAVs,” *Air Force Magazine*, August 2001, 61.

²⁶⁶ David Bowermaster, “Boeing’s Pilotless Fighter Could Make JSF Obsolete,” *Seattle Times*, 26 October 2001.

infrastructure.²⁶⁷ Finally, advanced technology systems will monitor UCAV performance and assist a small number of maintenance personnel in generating high sortie rates for extended conflicts.²⁶⁸ From the very beginning, supportability in UCAVs is a major design consideration that enhances both combat effectiveness and cost efficiency.

Conclusion

The military utility of all weapon systems must be balanced with their expense. While technological feasibility has traditionally held back the advancement of UCAVs, the potential for significant cost savings has stimulated their development. Development and procurement costs are essentially the same, but O&S costs for UCAVs may be much less than manned systems. This savings is currently offset by the very poor reliability, which decreases both combat effectiveness and cost efficiency. With increased reliability and excellent supportability, UCAVs can likely be both cost and operationally efficient.

²⁶⁷ Leahy, 10.

²⁶⁸ Ibid.

CHAPTER 7

CONCLUSIONS

Throughout the history of air power, the air-superiority fighter has had a pivotal role in the ability of military forces to gain and maintain air superiority. The attributes that have contributed to success in close- and long-range air-to-air engagements have been combined in the hybrid fighter. The desired characteristics for an air-superiority aircraft in the twenty-first century include: airframes capable of carrying the myriad of electronics and weapons that increase lethality; high-thrust, fuel efficient engines to enhance speed; excellent maneuverability and cockpit visibility; long range and loiter time; and stealth technology to increase survivability in the high threat combat arena of the future. The F-22 Raptor, which incorporates these characteristics, has been designed to conduct the mission of the air-superiority fighter for many years. It is this manned fighter that the air-superiority UCAV will strive to replace.

In 2025, the air-superiority UCAV will probably be technologically feasible. Advances in each of the air-superiority UCAV's three primary systems—air vehicle, ground control station, payload—will pave the way for a combat effective weapon system. Extensive improvements in airframe, flight control and propulsion technologies will enable air vehicles that are lethal, maneuverable, fast and survivable. Affordable stealth technology has been under development and is currently in use in both manned and unmanned systems. Advances in low-observable techniques that have benefited the F-22, Joint Strike Fighter (JSF), HiMAT and X-36 will also help the air-superiority UCAV. Adaptive smart wings that increase aircraft maneuverability, range and payload

are in the final phase of development at the DARPA. Reliable autonomous control has been demonstrated with the Global Hawk UAV and is the emphasis of continued research at both the AFRL and DARPA. Finally, the propulsion innovations being made in both the IHPTET and VAATE programs should yield high-performance engines for a low cost in the near future. Unmanned air vehicles with the potential to dominate their opposition should be possible by 2025.

Significant advances in data link capacity and autonomous capability should enable responsive and flexible mission management from the air-superiority UCAV ground control station. Airborne data link trends, improved data compression, efficient bandwidth modulation methods and a shift to laser data links should lead to satellite communications will allow sufficient bandwidth rates to permit reliable, simultaneous control of multiple air-superiority UCAV. If the rates of software progression can be increased while replacements to silicon technology are developed, autonomous control trends should continue to advance rapidly. The combination of adaptive, intelligent AI systems and expanded data transfer technology should permit a weapon system that is very responsive and combat-effective by 2025.

The payload on an air-superiority UCAV will make it lethal and survivable in the high-threat, air combat environment of the future. The weapons that turn a UAV into a UCAV are either currently in use or under development in the DOD. The ability to integrate them into a UCAV is a major design issue that must be considered, but should not be difficult. The sensors that detect, identify and target enemy aircraft can come from either onboard or offboard sensors. The quality of resolution, imaging, and identification capabilities for onboard radars are increasing rapidly at the same time that their weight

and cost are decreasing. Linked information networks of offboard sensors, on the other hand, are also progressing swiftly. The data link capability to share critical information between individual target nodes that permits cooperative target engagement has the potential to enable the feasibility of air-superiority UCAVs. Weapons and sensors unite to create payloads that may be combat-effective well into the future.

There is a potential for significant life cycle cost savings for an air-superiority UCAV. While effectiveness is a measure of capability to accomplish a mission, efficiency is the ability to accomplish that mission as a function of resources expended. Although R&D and procurement costs are essentially the same, unmanned O&S costs will be dramatically lower than those of manned systems. In wartime and peacetime alike, air-superiority UCAV should be extremely cost efficient. Their downfall, though, is in reliability. Technological efforts to increase reliability and high supportability characteristics will probably yield excellent operational efficiency by 2025. The air-superiority UCAV should be an affordable replacement to a manned air-superiority fighter by 2025.

Conclusion

Significant advances in air vehicle, control and payload technologies will make air-superiority UCAV feasible and effective in the future. As Colonel Michael Leahy, director of DARPA's X-45 UCAV program said, "there are no technological miracles needed to make a UCAV work."²⁶⁹ Low life cycle costs, enhanced reliability and supportability will make the system efficient. Air-superiority UCAV should provide an effective and affordable alternative to manned air-superiority fighters by 2025.

²⁶⁹ John A. Tirpak, "UCAVs Move Toward Feasibility," *Air Force Magazine*, March 1999, 34.

CHAPTER 8

IMPLICATIONS

From time to time a new invention astonishes the world, and is hailed by the prophets as the forerunner of a revolution in the military art. The cross-bow, the rifled barrel, the quick-firing gun, the submarine, the railway, and the motor-lorry—all these and others in their day have forcibly imposed important modifications in technique, and wrought great changes on the face of war. But all of them have had their counterpart in earlier ages, and none can really be said to have changed the nature of war.

— Air Marshall Jack C. Slessor

A combination of methods of automatic and remote control with homing devices will lead to a complete solution of the problem of pilotless aircraft, having tremendous speed, extraordinary range and ability to hit targets accurately. Although pilotless aircraft will never completely eliminate manned aircraft, they obviously will take over certain missions.

— **Theodore Von Karman**

The advances in technology that are currently occurring have the potential to significantly change the way the USAF and America conduct combat operations in this century. The air-superiority UCAV is a promising technology, but many risks and uncertainties remain. To ensure that air-superiority UCAVs have the best possible opportunity to develop and integrate into the USAF organizational structure, this study offers three conflicting implications for deliberation:

- An effective and affordable air-superiority UCAV may obviate the requirement to consider a manned replacement for the F-22 Raptor.

Long acquisition lead times and the extremely high development costs of new technologies mean that now may be the time to make a decision on future acquisition

programs. With the inevitability of lean budgets, the limited resources could be allocated to other high priority programs more appropriately. The simultaneous development of manned and unmanned systems that accomplish identical missions can result in an unnecessary diversion of resources from other essential mission areas. In my opinion, an air-superiority UCAV that is as effective as a manned platform while much more affordable should receive serious consideration for future development.

There will most likely be a time in the future when UCAVs will become more effective than manned fighter aircraft. These UCAVs will be highly maneuverable, stealthy, high-speed, and fully integrated into a complex network of sensors and information. As data transfer rates and artificial intelligence capabilities increase, the combat effectiveness of unmanned systems may surpass that of manned systems. When UCAVs can dominate manned fighter aircraft in all realms of mission execution they will no longer be merely an alternative but an imperative. It is unlikely this shift of dominance will occur by the year 2025. Until fully autonomous machines can reason like humans and make moral judgments, and until data transfer latency rates approach zero, there will be a role for humans in the cockpit. Current projections show that advanced processors that will simulate human cognitive processing may start to emerge as early as 2030. The further integration of this technology with numerous other advances will probably take many additional years. Although air-superiority UCAVs will most likely be technologically feasible by the year 2025, they will require still further development before they can supersede manned aircraft. Additionally, even if the U.S. could develop a dominant air-

superiority UCAV by the year 2025, there are no indications that a potential adversary could do the same. Until a foe can produce a system to defeat American manned aircraft superiority, the UCAV will remain an excellent alternative.

- Just because an air-superiority UCAV will be technologically feasible and economically affordable doesn't mean that they should necessarily replace manned fighters.

Technological feasibility asks if we *can* do something—is it possible; this implication asks if we *should* do something. Once technology makes air-superiority UCAVs militarily feasible, there are two other barriers to implementation. The first is a social revolution that results in widespread acceptance of alternative means of employing air power. Some critics of the USAF have said that it is reluctant to support UCAV technology because of its pro-pilot bias, commonly called the “white scarf syndrome.”²⁷⁰ Numerous authors investigating this syndrome, though, have found no evidence to support it.²⁷¹ On the contrary, they have shown that Air Force leaders seem to have “pursued aerospace technology of all kinds, even that which might reduce cockpit numbers.”²⁷² Only time will tell, but with an awareness of the potential for this bias Air Force leaders are taking steps to overcome it.

The final revolution that must take place is a political revolution. The desire to minimize risks to humans in combat has been an impetus to UCAV development. On the other side of the problem, though, little has been done to investigate the constraints

²⁷⁰ Carl Builder, *The Icarus Syndrome: The Role of Air Power Theory in the Evolution and Fate of the U.S. Air Force* (New Brunswick, N.J.: Transaction Publishers, 1994).

²⁷¹ For an excellent discussion disputing the white scarf syndrome, see Richard M. Clark, *Uninhabited Combat Aerial Vehicles: Airpower By the People, For the People, But Not With the People* (Maxwell AFB, Ala.: Air University Press, 2000).

²⁷² Thomas P. Ehrhard, “Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation,” (PhD diss., Johns Hopkins University, 1997) 496

incurred by conducting unmanned warfare. The moral and political implications of engaging in robotic warfare are numerous.²⁷³ Removing the pilot from the cockpit reduces his risk of capture, injury, or death but may possibly increase the susceptibility of others to fratricide or collateral damage. The human in a combat aircraft does much more than flying the vehicle and control weapons—at this point only human intelligence has the capacity to adapt to the rapidly changing, and sometimes very unexpected, circumstances of combat missions.²⁷⁴ Political leaders and decision makers will need to address these questions of added capability but increased risk and uncertainty before UCAVs replace manned systems.

- Manned and unmanned technologies are not mutually exclusive.

This study looked only at the ability of the air-superiority UCAV to replace the manned air-superiority fighter. Yes, the unmanned system may provide an effective and affordable alternative. The best answer, though, may be a mix of manned and unmanned aircraft that exploits the strengths and minimizes the weaknesses of both. Budgets are tight and money is scarce, but the synergistic union of these weapons could be the most effective and efficient alternative. For example, four multi-purpose UCAVs carrying AMRAAM could act as “wingmen” for a single manned F-22. The UCAVs could be relatively cheap because all expensive sensors could be carried aboard the F-22. Enemy aircraft would be detected, identified and finally targeted from UCAVs using the cooperative targeting information from a distributed information network and the F-22. The UCAV could enter the high-threat areas

²⁷³ Duncan Graham-Rowe, “Send In the Robots: Should We Let Machines Without a Conscience Go To War?” *New Scientist*, 13 October 2001, 3.

²⁷⁴ A. Noguier, “Next Mission Unmanned: The Human Factor in Air Power Tomorrow,” *Royal Air Force Air Power Review* (Winter 1999) 112.

while manned aircraft remain outside, alleviating the potential for the loss or capture of pilots. Humans are in the loop for all decision-making and weapons employment. High-bandwidth satellite data links for each UCAV would be unnecessary, as information could be relayed to each UCAV from the F-22 that would have line-of-sight contact with each aircraft. Multi-purpose UCAVs could be configured to carry air-to-air missiles today and air-to-ground weapons tomorrow. This would create great economies in the development and procurement of UCAV to further reduce their life cycle costs. The combination of manned and unmanned systems provides the potential to exploit the strengths, minimize weaknesses and reduce costs of a complete air superiority system.

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